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	Engineering and Design NAVSTAR GLOBAL POSITIONING SYSTEM SURVEYING	
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1 August 1996

US Army Corps
of Engineers

ENGINEERING AND DESIGN

NAVSTAR Global Positioning System Surveying

ENGINEER MANUAL

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

CECW-EP

Manual
No. 1110-1-1003

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Engineering and Design
NAVSTAR GLOBAL POSITIONING SYSTEM SURVEYING

1. Purpose. This manual provides technical specifications and procedural guidance for surveying with the NAVSTAR Global Positioning System (GPS). It is intended for use by engineering, topographic, or construction surveyors performing surveys for civil works and military construction projects. Procedural and quality control standards are defined to establish Corps-wide uniformity in GPS survey performance and GPS Architect-Engineer (A-E) contracts.

2. Applicability. This manual applies to HQUSACE elements, major subordinate commands (MSC), districts, laboratories, and field operating activities (FOA) having responsibility for the planning, engineering and design, operations, maintenance, construction, and related real estate and regulatory functions of civil works and military construction projects. It applies to GPS survey performance by both hired labor forces and contracted survey forces. It is also applicable to surveys performed or procured by local interest groups under various cooperative or cost-sharing agreements.

3. General. The NAVSTAR GPS has significantly modified many traditional survey practices found in all aspects of surveying and mapping work. The NAVSTAR GPS, operating in a differential or relative survey mode, is capable of providing far more accurate positions of either static monuments or moving platforms at costs far less than those for conventional survey methods. The goal of this manual is to ensure that GPS survey procedures are efficiently and uniformly practiced to attain more accurate and cost-effective surveying and mapping execution throughout the Corps of Engineers.

FOR THE COMMANDER:

ROBERT H. GRIFFIN
Colonel, Corps of Engineers
Chief of Staff

This manual supersedes EM 1110-1-1003, dated 31 December 1994.

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Chapter 1
Introduction

1-1. Purpose

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1-3. References

Required and related publications are listed in Appendix A.

1-4. Explanation of Abbreviations and Terms

GPS surveying terms and abbreviations used in this manual are explained in the Glossary (Appendix B).

1-5. Trade Name Exclusions

The citation or illustration in this manual of trade names of commercially available GPS products, including other auxiliary surveying equipment, instrumentation, and adjustment software, does not constitute official endorsement or approval of the use of such products.

1-6. Accompanying Guide Specification

A guide specification for the preparation of A-E contracts for GPS survey services is contained in Appendix G.

1-7. Background

GPS surveying is a process by which highly accurate, three-dimensional (3D) point positions are determined from signals received from NAVSTAR satellites. GPS-derived positions may be used to provide the primary reference control monument locations for engineering and construction projects, from which detailed site plan topographic mapping, boundary demarcation, and construction alignment work may be performed using conventional surveying instruments and procedures. GPS surveying also has application in the continuous positioning of marine floating plants. GPS surveying can also be used for input to Geographic Information System (GIS) and mapping projects.

1-8. Scope of Manual

This manual deals primarily with the use of differential carrier phase GPS survey techniques for establishing and/or extending project construction or boundary control. Both static and kinematic survey methods are covered, along with related GPS data reduction, post-processing, and adjustment methods. Differential code phase GPS positioning and navigation methods supporting hydrographic surveying and dredge control are covered to a lesser extent (see EM 1110-2-1003 for further information on hydrographic surveying with GPS). Kinematic (or dynamic) real-time differential carrier phase GPS surveying applications are covered in detail in this manual. Absolute GPS point positioning methods (i.e., nondifferential) are also described since these techniques have an application in some USACE surveying and mapping projects.

a. This manual is intended to be a comprehensive reference guide for differential carrier phase GPS surveying, whether performed by in-house, hired-labor forces, contracted forces, or combinations thereof. General planning criteria, field and office execution procedures, and required accuracy specifications for performing differential GPS surveys in support of USACE engineering, construction, operations, planning, and real estate activities are provided. Accuracy specifications, procedural criteria, and quality control requirements contained in this manual shall be directly referenced in the scopes of work for A-E survey services or other third-party survey services. This is intended to ensure that uniform and standardized procedures are followed by both hired-labor and contract service sources throughout USACE.

b. The primary emphasis of the manual centers on performing second- and third-order accuracy surveys. This accuracy level will provide adequate reference control from which supplemental real estate, engineering, construction layout surveying, and site plan topographic mapping work may be performed using conventional survey techniques. Therefore, the survey criteria given in this manual will not necessarily meet the Federal Geodetic Control Subcommittee (FGCS) standards and specifications required for the National Geodetic Reference System (NGRS). However, it should be understood that following the methods and procedures given in this manual will give final results generally equal to or exceeding FGCS second-order relative accuracy criteria. This is adequate for the majority of USACE projects.

c. Chapter 12 herein on GPS cost estimating is intended to assist those USACE Commands which primarily contract out survey services. Refer to Appendix G for further information concerning the contracting of GPS services.

d. This manual briefly covers the theory and physical concepts of NAVSTAR GPS positioning. Consult the related publications in Appendix A for further information.

1-9. Life Cycle Project Management Applicability

Project control established by GPS survey methods may be used through the entire life cycle of a project, spanning decades in many cases. During initial reconnaissance surveys of a project, control established by GPS should be permanently monumented and situated in areas that are conducive to the performance or densification of subsequent surveys for contract plans and specifications, construction, and maintenance. During the early planning phases of a project, a comprehensive survey control plan should be developed which considers survey requirements over a project's life cycle, with a goal of eliminating duplicative or redundant surveys to the maximum extent possible.

1-10. Metrics

Metric units are used in this manual. Metric units are commonly used in geodetic surveying applications, including the GPS survey work covered herein. GPS-derived geographical or metric Cartesian coordinates are generally transformed to non-SI units of measurements for use in local project reference and design systems, such as State Plane Coordinate System (SPCS) grids. In all cases, the use of metrics shall follow local engineering and construction practices. Non-SI/metric equivalencies are noted where applicable, including the critical--and often statutory--distinction between the U.S. Survey Foot (1,200/3,937 m exactly) and International Foot (30.48/100 m exactly) conversions.

1-11. Manual Development and Proponency

The HQUSACE proponent for this manual is the Surveying and Analysis Section, General Engineering Branch, Civil Works Directorate. The manual was developed by the U.S. Army Topographic Engineering Center (USATEC) during the period 1992-1994 under the Civil Works Guidance Update Program, U.S. Army Engineer Waterways Experiment Station. Primary technical authorship and/or review was provided by the U.S. Army Engineer Districts, Pittsburgh, Tulsa, Detroit, New Orleans, and St. Louis. Recommended corrections or modifications to this manual should be directed to HQUSACE, ATTN: CECW-EP-S, 20 Massachusetts Ave. NW, Washington, DC 20324-1000.

1-12. Distribution

Copies of this document or any other Civil Works Criteria Documents can be obtained from: U.S. Army Corps of Engineers, Publications Depot, 2803 52nd Ave, Hyattsville, MD 20781-1102, Phone: (301) 394-0081.

1-13. Further Information

Further information on the technical contents of this manual can be obtained from:

U.S. Army Topographic Engineering Center
ATTN: CETEC-TD-AG
Surveying Division
7701 Telegraph Road
Alexandria, VA 22315-3864

Phone: (703) 428-6766
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Chapter 2
Operational Theory of NAVSTAR GPS

This chapter provides a general overview of the basic operating principles and theory of the NAVSTAR GPS. The references listed in Appendix A should be used for more detailed background of all the topics covered in this chapter.

2-1. Global Positioning System (GPS)

The NAVSTAR GPS is a passive, satellite-based, navigation system operated and maintained by the Department of Defense (DoD). Its primary mission is to provide passive global positioning/navigation for land-, air-, and sea-based strategic and tactical forces. A GPS receiver is simply a range measurement device; distances are measured between the receiver antenna and the satellites, and the position is determined from the intersections of the range vectors. These distances are determined by a GPS receiver which precisely measures the time it takes a signal to travel from the satellite to the station. This measurement process is similar to that used in conventional pulsing marine navigation systems and in phase comparison electronic distance measurement (EDM) land surveying equipment.

a. GPS operating and tracking modes. There are basically two general operating modes from which GPS-derived positions can be obtained: absolute positioning and relative or differential positioning. Within each of these two modes, range measurements to the satellites can be performed by tracking either the phase of the satellite's carrier signal or the pseudo-random noise codes modulated on the carrier signal. In addition, GPS positioning can be performed with the receiver operating in a static or dynamic (kinematic) environment. This variety of operational options results in a wide range of accuracy levels which may be obtained from the NAVSTAR GPS. Accuracies can range from 100 m down to the sub-centimeter level, as shown in Figure 2-1. Increased accuracies to the sub-centimeter level require additional observing time and, until recently, could not be achieved in real time. Selection of a particular GPS operating and tracking mode (i.e., absolute, differential, code, carrier, static, kinematic, or combinations thereof) depends on the user application. USACE survey applications typically require differential positioning using carrier phase tracking. Some dredge control and hydrographic applications can use differential code measurements. Absolute modes are rarely used for geodetic surveying applications except when worldwide reference control is being established.

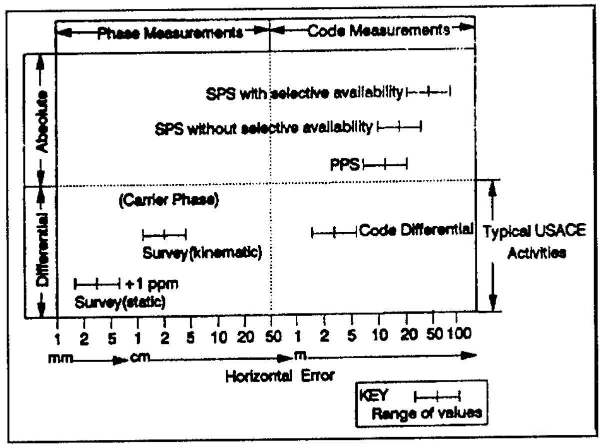


Figure 2-1. GPS operating modes and accuracies

b. Absolute positioning. The most common military and civil (i.e., commercial) application of GPS is "absolute positioning" for real-time navigation. When operating in this passive, real-time navigation mode, ranges to NAVSTAR satellites are observed by a single receiver positioned on a point for which a position is desired. This receiver may be positioned to be stationary over a point (i.e., static, Figure 2-2) or in motion (i.e., kinematic positioning, such as on a vehicle, aircraft, missile, or backpack). Two levels of absolute positioning accuracy may be obtained from the NAVSTAR GPS. These are called the (1) Standard Positioning Service (SPS) and (2) Precise Positioning Service (PPS).

(1) Using the SPS, the user is able to achieve real-time 3D absolute point positioning on the order of 100 m. The SPS is the GPS signal that the DoD authorizes to civil users. This level of accuracy, achievable by the civil user, is due to the deliberate degradation of the GPS signal by the DoD for national security reasons. DoD degradation of the GPS signal is referred to as "Selective Availability" or S/A. DoD has also implemented Anti-Spoofing or A-S which will deny the SPS user the more accurate P-code. S/A and A-S will be discussed further in Chapter 5.

(2) Use of the PPS requires authorization by DoD to have a decryption device capable of deciphering the encrypted GPS signals. USACE is an authorized user; however, actual use of the equipment has security implications. Real-time 3D absolute positional accuracies of 16-20 m are attainable through use of the PPS.

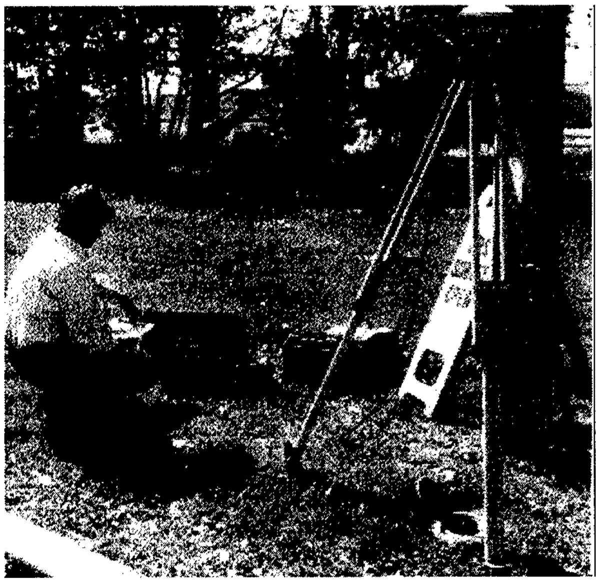


Figure 2-2. Performing static differential GPS surveys

(3) With certain specialized GPS receiving equipment, data processing refinements, and long-term static observations, absolute positional coordinates may be determined to accuracy levels less than a meter. Applications of this are usually limited to worldwide geodetic reference surveys.

(4) These absolute point positioning accuracy levels are not suitable for USACE surveying applications other than rough reconnaissance work or general vessel navigation. They may be useful for some military topographic surveying applications (e.g., artillery surveying).

c. Differential or relative GPS positioning. Differential positioning is simply a process of measuring the differences in coordinates between two receiver points, each of which is simultaneously observing/measuring satellite code ranges and/or carrier phases from the NAVSTAR GPS constellation. The process actually involves the measurement of the difference in ranges between the satellites and two or more ground observing points. The range measurement is performed by a phase difference comparison, using either the carrier phase or code phase. The basic principle is that the absolute positioning errors at the two receiver points will be approximately the same for a given instant. The resultant accuracy of these coordinate differences is at the meter level for code phase observations and at the centimeter level for carrier phase tracking. These coordinate differences are usually expressed as 3D "baseline vectors," which are comparable to conventional survey azimuth/distance measurements. Differential GPS (DGPS) positioning can be performed in either a static or kinematic mode. Further information on DGPS can be found in Chapter 6.

2-2. NAVSTAR Program Background

A direct product of the "space race" of the 1960's, the NAVSTAR GPS is actually the result of the merging of two independent programs that were begun in the early 1960's: the U.S. Navy's TIMATION Program and the U.S. Air Force's 621B Project. Another system similar in basic concept to the current NAVSTAR GPS was the U.S. Navy's TRANSIT program, which was also developed in the 1960's. Currently, the entire system is maintained by the NAVSTAR GPS Joint Program Office (JPO), a North Atlantic Treaty Organization (NATO) multiservice type organization. DoD originally designed the NAVSTAR GPS to provide sea, air, and ground forces of the United States and members of NATO with a unified, high-precision, all-weather, worldwide, real-time positioning system. Mandated by Congress, GPS is freely used by both the military and civilian public for real-time absolute positioning of ships, aircraft, and land vehicles, as well as highly precise differential point positioning.

2-3. NAVSTAR System Configuration

The NAVSTAR GPS consists of three distinct segments: the space segment (satellites), the control segment (ground tracking and monitoring stations), and the user segment (air-, land-, and sea-based receivers). See Figure 2-3 for a representation of the basic GPS system segments.

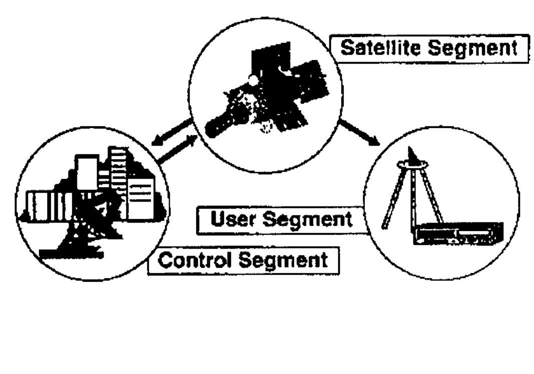


Figure 2-3. GPS system segments

a. Space segment. The space segment consists of all GPS satellites in orbit. The first generation of satellites was the Block I or developmental. Several of these are still operational. A full constellation of Block II or production satellites is presently being put into orbit using Delta II launch vehicles. *The full 24-satellite constellation is scheduled to be in orbit by early FY94.* When this full constellation is implemented, there will be 24 Block II operational satellites (21 primary with 3 active on-orbit spares). There will be four satellites in each of six orbital planes inclined at 55 deg to the equator. The satellites will be at altitudes of 10,898 nm (20,183 km), and have 11-hr-56-minute orbital periods. The three active spares will be transparent to the user on the ground; i.e., the user will not be able to tell which are operational satellites and which are spares. A procurement action for Block IIR (R is for replacement) satellites is underway, thus ensuring full system performance through the year 2025. Figure 2-4 illustrates some of the common design characteristics of the NAVSTAR GPS fully configured Block IIR constellation.

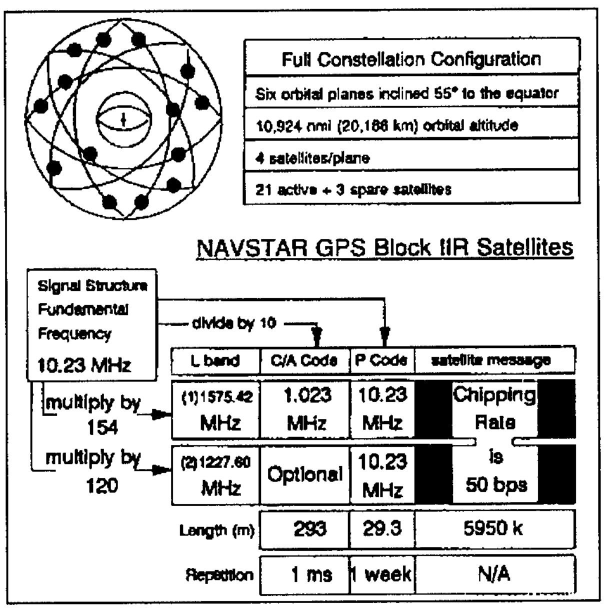


Figure 2-4. NAVSTAR GPS Block IIR constellation

b. Control segment. The GPS control segment consists of five tracking stations located throughout the world (Figure 2-5). These stations are in Hawaii, Colorado, Ascension Island, Diego Garcia, and Kwajalein. The information obtained from tracking the satellites is used in controlling the satellites and predicting their orbits. Three of the stations (Ascension, Diego Garcia, and Kwajalein) are used for transmitting information back to the satellites. The Master Control Station is located at Colorado Springs, Colorado. All data from the tracking stations are transmitted to the Master Control Station where they are processed and analyzed. Ephemerides, clock corrections, and other message data are then transmitted back to the three stations for subsequent transmittal back to the satellites. The Master Control Station is also responsible for the daily management and control of the GPS satellites and the overall control segment.

c. User segment. The user segment represents the ground-based receiver units that process the NAVSTAR satellite signals and arrive at a position of the user. It consists of both military and civil activities for an almost unlimited number of applications in a variety of air-, sea-, or land-based platforms. Land surveying applications (including those of USACE) represent a small percentage of current and potential GPS users.

2-4. GPS Broadcast Frequencies and Codes

Each NAVSTAR satellite transmits signals on two L-band frequencies, designated as L1 and L2. The L1 carrier frequency is 1575.42 megahertz (MHz) and has a wavelength of approximately 19 centimeters (cm). The L2 carrier frequency is 1227.60 MHz and has a wavelength of approximately 24 cm. The L1 signal is modulated with a Precise Code (P-code) and a Coarse Acquisition Code (C/A-code). The L2 signal is modulated with only the P-code. Each satellite carries precise atomic clocks to generate the timing information needed for precise positioning. A navigation message is also transmitted on both frequencies. This message contains ephemerides, clock correction and coefficients, health and status of satellites, almanacs of all GPS satellites, and other general information.

a. Pseudo-random noise. The modulated C/A- and P-codes are referred to as pseudo-random noise (PRN). This pseudo-random code is actually a sequence of very precise time marks that permit the ground receivers to compare and compute the time of transmission between the satellite and ground station. From this transmission time, the range to the satellite can be derived. This is the basis behind GPS range measurements. The C/A-code pulse intervals are approximately every 300 m in range and the more accurate P-code every 30 m.

b. Pseudo-ranges. A pseudo-range is the time delay between the satellite clock and the receiver clock, as determined from C/A- or P-code pulses. This time

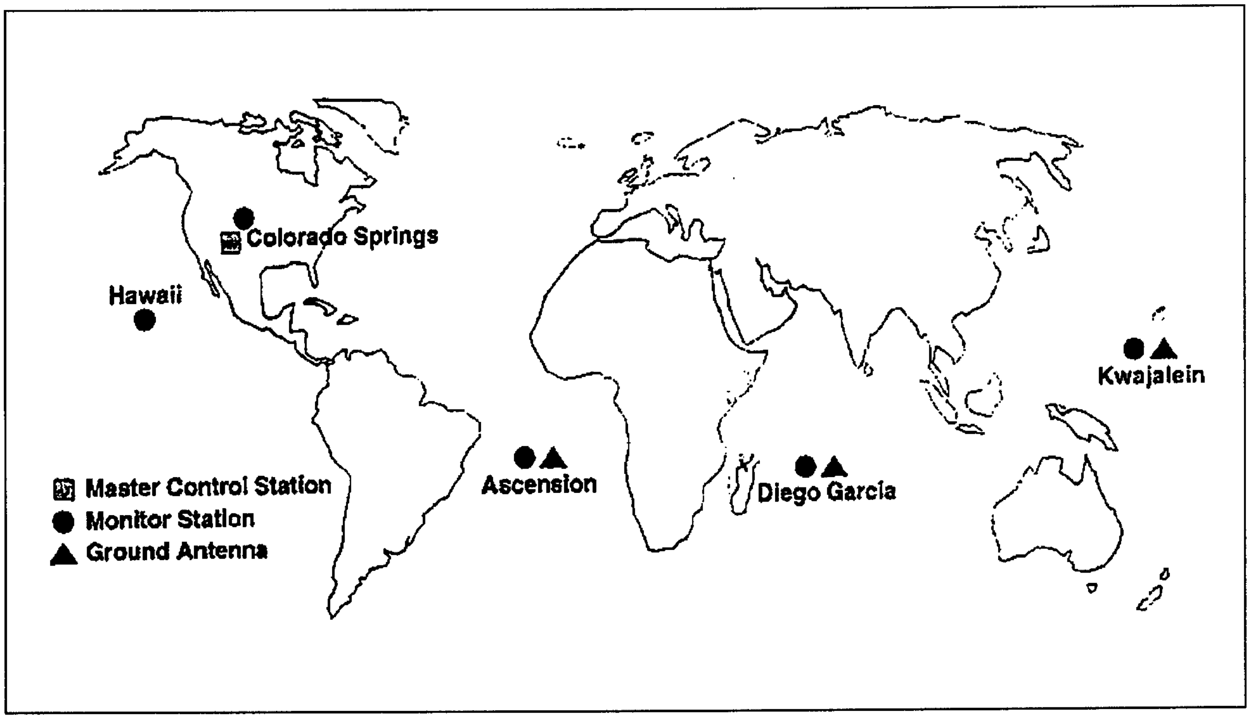


Figure 2-5. GPS control station network

difference equates to the range measurement but is called a pseudo-range since at the time of the measurement, the receiver clock is not synchronized to the satellite clock. In most cases, an absolute 3D real-time navigation position can be obtained by observing at least four simultaneous pseudo-ranges.

c. SPS. The SPS uses the less precise C/A-code pseudo-ranges for real-time GPS navigation. Due to deliberate DoD degradation of the C/A-code accuracy, 100 m in horizontal and 156 m in vertical accuracy levels result. These accuracy levels are adequate for most civil or nonmilitary applications, where only approximate real-time navigation is required.

d. PPS. The PPS is the fundamental military real-time navigation use of GPS. Pseudo-ranges are obtained using the higher pulse rate (i.e., higher accuracy) P-code on both frequencies (L1 and L2). Real-time 3D accuracies at the 16-m level (and 10 m horizontal) can be achieved with the PPS. The P-code is encrypted to prevent unauthorized civil or foreign use. This encryption will require a special key to obtain this 16-m accuracy. These accuracies are adequate for some USACE surveying and mapping projects (i.e. GIS database input).

e. Carrier phase measurements. Carrier frequency tracking measures the phase differences between the Doppler shifted satellite and receiver frequencies. The phase differences are continuously changing due to the changing satellite earth geometry. However, such effects are resolved in the receiver and subsequent data post-processing. When carrier phase measurements are observed and compared between two stations (i.e., relative or differential mode), baseline vector accuracy between the stations below the centimeter level is attainable in three dimensions. New receiver technology and processing techniques have allowed for carrier phase measurements to be used in real-time centimeter positioning.

2-5. GPS Broadcast Messages and Ephemeris Data

Each NAVSTAR GPS satellite periodically broadcasts data concerning clock corrections, system/satellite status, and most critically, its position or ephemeris data. There are two basic types of ephemeris data: broadcast and precise.

a. Broadcast ephemerides. The broadcast ephemerides are actually predicted satellite positions broadcast

within the navigation message that are transmitted from the satellites in real time. The ephemerides can be acquired in real time by a receiver capable of acquiring either the C/A- or P-code. The broadcast ephemerides are computed using past tracking data of the satellites. The satellites are tracked continuously by the monitor stations to obtain more recent data to be used for the orbit predictions. The data are analyzed by the Master Control Station, and new parameters for the satellite orbits are transmitted back to the satellites. This upload is performed daily with new predicted orbital elements transmitted every hour by the navigation message.

b. Precise ephemerides. The precise ephemerides are based on actual tracking data that are post-processed to obtain the more accurate satellite positions. These ephemerides are available at a later date and are more accurate than the broadcast ephemerides because they are based on actual tracking data and not predicted data. Nonmilitary users can obtain this information from the National Geodetic Survey (NGS) or from private sources that maintain their own tracking networks and provide information for a fee. For most USACE survey applications, the broadcast ephemerides are adequate to obtain the needed accuracies.

c. See Appendix D for sources of GPS information and its status.

Chapter 3
GPS Applications in USACE

3-1. General

Currently, surveyors use GPS to increase their efficiency, productivity, and to produce more accurate results. GPS can be used for real estate surveys, regulatory enforcement actions, horizontal and vertical control densification, structural deformation studies, airborne photogrammetry, dynamic positioning and navigation for hydrographic survey vessels and dredges, hydraulic study/survey location, river/floodplain cross-section location, core drilling location, environmental studies, levee overbank surveys, and levee profiling. Future construction uses of dynamic GPS are unlimited: levee grading and revetment placement, disposal area construction, grade control, etc. Additionally, GPS has application in developing various levels of GIS spatial data. A few of these applications are briefly described in this chapter.

3-2. Project Control Densification

Establishing or densifying project control with GPS is often cost-effective, faster, more accurate, and more reliable than conventional survey methods. The quality control statistics and large number of redundant measurements in GPS networks help to ensure reliable results. Field operations to perform a GPS survey are relatively easy and can generally be performed by one person per receiver. GPS is particularly attractive for control networks as compared with conventional surveys because intervisibility is not required between adjacent stations.

3-3. Geodetic Control Densification

GPS can be used for wide-area high-order geodetic control densification. GPS provides very precise point positioning (when used in a relative mode), producing baseline results on the order of 5 to 10 ppm under average conditions.

3-4. Vertical Control Densification

GPS uses the World Geodetic System of 1984 (WGS 84) ellipsoid as the optimal mathematical model describing the shape of the earth on an ellipsoid of rotation. There is no direct mathematical relation between heights obtained from GPS and orthometric elevations obtained from conventional spirit leveling. However, a model can be determined from benchmark data and corresponding GPS data. This model can then be used to derive the unknown orthometric heights of stations occupied during a GPS observation period to densify supplemental small-scale topographic mapping. Geoid modeling software also exists and is used to determine orthometric heights from GPS. Extreme caution should be taken in using GPS for vertical densification. The procedures for vertical densification are described in further detail in Chapter 6.

3-5. Structural Deformation Studies

GPS survey techniques can be used to monitor the motion of points on a structure relative to stable monuments. This can be done with an array of antennae positioned at selected points on the structure and on remote stable monuments. Baselines are formulated between the occupied points to monitor differential movement. The relative precision of the measurements is on the order of ±5 mm over distances averaging between 5 and 10 km. Measurements can be made on a continuous basis. A GPS structural deformation system can operate unattended and is relatively easily installed and maintained.

3-6. Photogrammetry

The use of an airborne GPS receiver employing on-the-fly (OTF) techniques combined with specialized photogrammetric procedures has the potential to significantly reduce the amount of ground control for typical photogrammetric projects. Currently, these projects require a significant amount of manpower and monetary resources for the establishment of the control points. Therefore, the use of this GPS Controlled Photogrammetry (GCP) technology in the USACE civil works programs should reduce the production costs associated with large scale maps. The benefits of GCP will be realized in the savings estimation based on the premise that most of the USACE photogrammetry activities require USACE personnel to do much planning and surveying in preparation for the actual photogrammetry flight, and the GCP procedure has the potential for the reduction, or even elimination, of this surveying activity. Tests have shown that ground control coordinates can be developed from an airborne platform using adapted GPS kinematic techniques to centimeter-level precision in all three axes if system-related errors are minimized and care is taken in conduct of the GPS and photogrammetric portions of the procedures. High quality photogrammetric results can also be achieved with DGPS based on carrier-smoothed code phase positioning.

3-7. Dynamic Positioning and Navigation

Dynamic, real-time GPS code and carrier phase positioning of construction and surveying platforms has the potential for revolutionizing many current USACE design and construction functions. This includes dredge control systems, site investigation studies/surveys, horizontal and vertical construction placement, hydraulic studies, or any other activity requiring dimensional control. Real-time, centimeter-level 3D (based on the WGS 84 Ellipsoid) control may be achieved using carrier phase differential GPS; this method can be used for any type of construction or survey platform (e.g., dredges, graders, survey vessels, etc.). This method is discussed further in Chapter 6.

3-8. GIS Integration

A GIS is an effective means to correlate and store diverse information on natural or man-made characteristics of geographic positions. In order for a GIS to be reliably oriented, it should be based on a coordinate system. A standardized GIS network enables a more accurate exchange of GIS information between databases. In recent years, GPS has demonstrated its efficiency, cost effectiveness, and accuracy in precise surveying and mapping support.

Chapter 4
GPS Reference Systems

4-1. General

In order to fully understand GPS, and its positional information, it is important to understand the reference system on which it is based. The GPS satellites are referenced to the WGS 84 ellipsoid. For surveying purposes, this earth-centered WGS 84 coordinate system must be converted (i.e., transformed) to a user-defined ellipsoid/datum, such as the Clarke 1866 (North American Datum of 1927 (NAD 27)) or Geodetic Reference System of 1980 (GRS 80) reference ellipsoids. Differential positioning provides this conversion by locating one of the receivers at a known point on the user's datum. This chapter deals with GPS reference systems and datums to which GPS coordinates can be transformed.

4-2. Geodetic Coordinate Systems

The absolute positions obtained directly from GPS pseudo-range measurements are based on the 3D, earth-centered WGS 84 ellipsoid. Coordinate outputs are on a Cartesian system (X, Y, and Z) relative to an Earth Centered Earth Fixed (ECEF) Rectangular Coordinate System having the same origin as the WGS 84 ellipsoid, i.e. geocentric. This geocentric X-Y-Z coordinate system should not be confused with the X-Y plane coordinates established on local grids; local systems usually have entirely different definitions, origins, and orientations which require certain transformations to be performed. WGS 84 Cartesian coordinates can be easily converted into WGS 84 ellipsoid coordinates (i.e., ϕ, λ, and h, geodetic latitude, longitude, and height, respectively).

4-3. WGS 84 Reference Ellipsoid

a. The origin of the WGS 84 Cartesian system is the earth's center of mass. The Z-axis is parallel to the direction of the Conventional Terrestrial Pole (CTP) for polar motion, as defined by the Bureau International Heure (BIH), and equal to the rotation axis of the WGS 84 ellipsoid. The X-axis is the intersection of the WGS 84 reference meridian plane and the CTP's equator, the reference meridian being parallel to the zero meridian defined by the BIH and equal to the X-axis of the WGS 84 ellipsoid. The Y-axis completes a right-handed, earth-centered, earth-fixed orthogonal coordinate system, measured in the plane of the CTP equator 90 deg east of the X-axis and equal to the Y-axis of the WGS 84 ellipsoid. This system is illustrated in Figure 4-1.

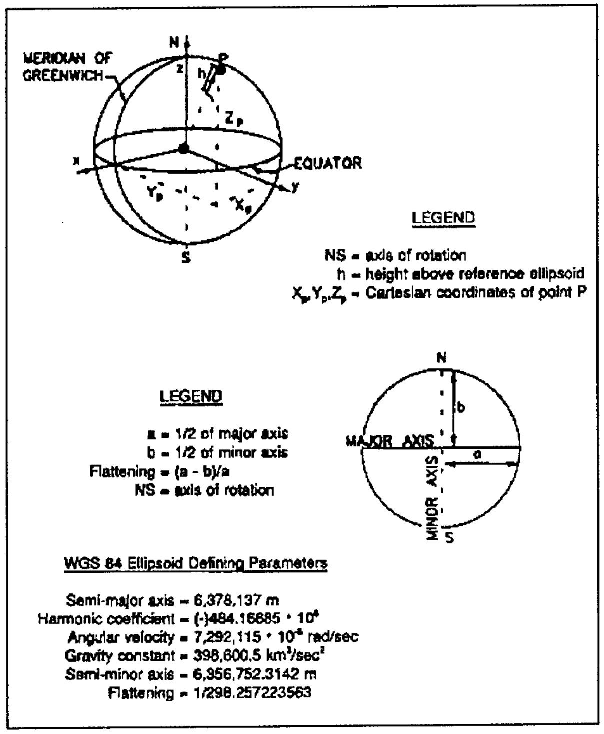


Figure 4-1. GPS WGS 84 reference ellipsoid

b. Prior to development of WGS 84, there were several reference ellipsoids and interrelated coordinate systems (datums) that were used by the surveying community. Table 4-1 lists just a few of these systems, some of which are widely used even today.

Table 4-1
Reference Ellipsoids and Related Coordinate Systems

Reference Ellipsoid	Coordinate System (Datum)
Clarke 1866	NAD 27
WGS 72	WGS 72
GRS 80	NAD 83
WGS 84	WGS 84

4-4. Horizontal Positioning Datums

One USACE application of differential GPS surveying is in densifying military construction and civil works project control. This densification is usually done relative to an existing datum (NAD 27, NAD 83, or local). Even though GPS measurements are made relative to the WGS 84 ellipsoidal coordinate system, coordinate differences (i.e., baseline vectors) on this system can, for

practical engineering purposes, be used directly on any local user datum. Thus, a GPS-coordinated WGS 84 baseline can be directly used on an NAD 27, NAD 83, or even a local project datum. Minor variations between these datums will be minimal when GPS data are adjusted to fit between local datum stations. Such assumptions may not be valid when high-order NGRS network densification work is being performed.

a. North American Datum of 1927 (NAD 27). NAD 27 is a horizontal datum based on a comprehensive adjustment of a national network of traverse and triangulation stations. NAD 27 is a best fit for the continental United States. The fixed datum reference point is located at Meades Ranch, Kansas. The longitude origin of NAD 27 is the Greenwich Meridian with a south azimuth orientation. The original network adjustment used 25,000 stations. The relative precision between initial point monuments of NAD 27 is by definition 1:100,000, but coordinates on any given monument in the network contain errors of varying degrees. As a result, relative accuracy between points on NAD 27 may be far less than the nominal 1:100,000. The reference units for NAD 27 are U.S. Survey Feet.

b. North American Datum of 1983 (NAD 83). NAD 83 uses many more stations and observations than NAD 27, including some satellite-derived coordinates, to readjust the national network (a total of approximately 250,000 stations were used). The longitude origin of NAD 83 is the Greenwich Meridian with a north azimuth orientation. NAD 83 has an average precision of 1:300,000. NAD 83 is based upon the GRS 80, an earth-centered reference ellipsoid, and for most practical purposes is equivalent to WGS 84, which is currently the best available geodetic model of the shape of the earth surface worldwide. The reference units for NAD 83 are meters.

c. HARNs Network Survey Datum. The nationwide horizontal reference network was redefined in 1983 and readjusted in 1986 by the NGS. It is known as the North American Datum of 1983, adjustment of 1986, and is referred to as NAD 83 (86). It is accurate to 1 part in 100,000 which normally satisfies USACE surveying, mapping, and related spatial database requirements. USACE adopted this datum on 5 March 1990. Since that time, several states and the NGS have begun developing High Accuracy Reference Networks (HARNs) for surveying, mapping, and related spatial database projects. These networks, developed exclusively with GPS, are accurate to 1 part in 1,000,000. HARNs have a slightly different coordinate, usually within one meter of those in NAD 83 (86), resulting in two coordinate values for the same survey point. Since the confusion and potential litigation inherent with multiple coordinates with the same point can adversely impact design, construction, boundary location, and other functions, use of HARNS is not recommended.

d. Geodetic survey datums. GPS uses the WGS 84 reference ellipsoid for geodetic survey purposes. GPS routinely provides differential horizontal positional results on the order of 1 ppm, compared to the accepted results of 1:300,000 for NAD 83 and (approximately) 1:100,000 for NAD 27. Even though GPS has such a high degree of precision, it provides only coordinate differences; therefore, ties to the national network to obtain coordinates of all GPS stations must be done without distorting the established control network (i.e., degrade the GPS-derived vectors during the adjustment). Generally, on midsize survey projects, three or more horizontal control stations from the national network can be used during the GPS observation scheme. In order to facilitate a tie between GPS and existing networks for horizontal control, an adjustment of the whole network scheme (all control and GPS-derived points) should be completed. There are many commercial software packages that can be used to perform this adjustment. Once a network adjustment meets the accuracy requirement, those values should not be readjusted with additional points or observations.

e. Local project datums. Several projects can be based on local project datums. These local datums might be accurate within a small area, but can become distorted over larger areas. Most local project datums are not connected to any other datums, but can be tied to outside control and related and transformed to another datum. It is important to understand how this local datum was established in order to relate it or perform a transformation to some other datum.

f. State Plane Coordinate System. The SPCS was developed by the NGS to provide a planar representation of the earth's surface. To properly relate spherical coordinates (ϕ,λ) to a planar system (Northings and Eastings), a developable surface must be constructed. A developable surface is defined as a surface that can be expanded without stretching or tearing. The two most common developable surfaces or map projections used in surveying and mapping are the cone and cylinder. The projection of choice is dependent on the north-south or east-west extent of the region. Areas with limited east-west dimensions and elongated north-south extent utilize the Transverse Mercator projection. Areas with limited north-south dimensions and elongated east-west extent utilize the

Lambert projection. For further information on the State Plane Coordinate System see EM 1110-1-1004.

4-5. Orthometric Elevations

Orthometric elevations are those corresponding to the earth's irregular geoidal surface. Measured differences in elevation from spirit leveling are generally relative to geoidal heights--a spirit level bubble (or pendulum) positions the instrument normal to the direction of gravity, and thus parallel with the local slope of the geoid. Elevation differences between two points are orthometric differences, a distinction particularly important in river/channel hydraulics. Orthometric heights for the continental United States (CONUS) are generally referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29) or the North American Vertical Datum of 1988 (NAVD 88); however, other vertical datums may be used in some projects (e.g., the International Great Lakes Datum of 1955 (IGLD 55) or International Great Lakes Datum of 1985 (IGLD 85)), which is a dynamic/hydraulic-based datum, not an orthometric datum).

4-6. GPS WGS 84 Ellipsoidal Heights

GPS-determined heights or height differences are referenced to an idealized mathematical ellipsoid, i.e., WGS 84. This WGS 84 ellipsoid differs significantly from the geoid; thus, GPS heights are not the same as the orthometric heights which are needed for standard USACE projects (i.e. local engineering, construction, and hydraulic measurement functions). (See Figure 4-2.) Accordingly, any WGS-84-referenced height obtained using GPS must be transformed to the local orthometric vertical datum. This requires adjusting and interpolating GPS-derived heights relative to fixed orthometric elevations. Such a process may or may not be of suitable accuracy (i.e. reliability) for some engineering and construction work. See Table 6-1 in Chapter 6.

4-7. Orthometric-WGS 84 Elevation Relationship

The relationship between a WGS 84 ellipsoidal height and an orthometric height relative to the geoid can be obtained from the following equation:

$$h = H + N \tag{4-1}$$

where

h = ellipsoidal height

H = elevation (orthometric)

N = geoid undulation

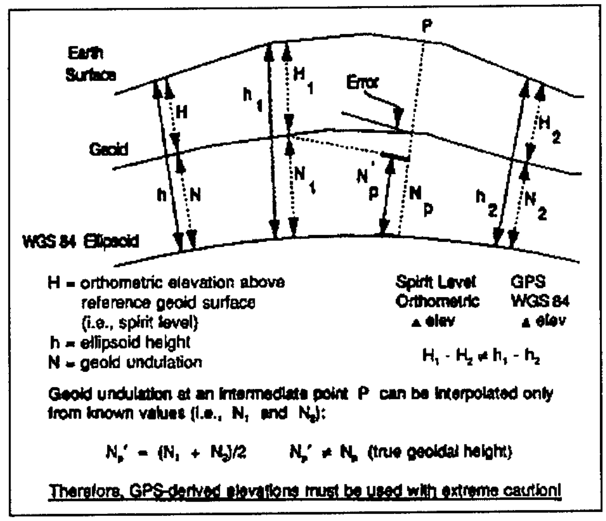


Figure 4-2. GPS ellipsoid heights

a. Due to significant variations in the geoid, even over small distances, elevation differences obtained by GPS cannot be directly equated to orthometric (or spirit level) differences. Geoid modeling techniques are often used to obtain the parameter N in Equation 4-1; however, accuracies may not be adequate for engineering purposes. Some small project areas where the geoid stays fairly constant or local geoid modeling can be performed, elevation differences obtained by GPS can be used. See Chapter 6 for further information on the concept of vertical densification with GPS.

b. GPS surveys can be designed to provide elevations of points on the local vertical datum. This requires connecting to a sufficient number of existing orthometric benchmarks from which the elevations of unknown points can be "best fit" by some adjustment method--usually a least squares minimization. This is essentially an interpolation process and assumes linearity in the geoid slope between two established benchmarks. If the geoid variation is not linear, then the adjusted (interpolated) elevation of an intermediate point will be in error. Depending on the station spacing, location, local geoid undulations, and numerous other factors, the resultant interpolated/adjusted elevation accuracy is usually not suitable for construction surveying purposes; however, GPS-derived elevations may be adequate for small-scale topographic mapping control.

Chapter 5
GPS Absolute Positioning Determination Concepts, Errors, and Accuracies

5-1. General

NAVSTAR GPS determination of a point position on the earth actually uses techniques common to conventional surveying trilateration: an electronic distance measurement resection. The user's receiver simply measures the distance (i.e., ranges) between the earth and the NAVSTAR GPS satellite(s). The user's position is determined by the resected intersection of the observed ranges to the satellites. Each satellite range creates a sphere which forms a circle (approximately) upon intersection with the earth's surface. Given observed ranges to two different satellites, two intersecting circles result from which a horizontal (2D) position on the earth can be computed. Adding a third satellite range creates three spheres, the intersection point of which will provide the X-Y-Z geocentric coordinates of a point. Adding more satellite ranges will provide redundancy in the positioning, which allows adjustment. In actual practice, at least four satellite observations are required in order to resolve timing variations for a 3D position.

5-2. Absolute Positioning

Absolute positioning involves the use of only a single passive receiver at one station location to collect data from multiple satellites in order to determine the station's location. It is not sufficiently accurate for precise surveying or hydrographic positioning uses. It is, however, the most widely used military and commercial GPS positioning method for real-time navigation and location (see paragraph 2-1*b*).

a. The accuracies obtained by GPS absolute positioning are dependent on the user's authorization. The SPS user can obtain real-time point positional accuracies of 100 m. The lower level of accuracies achievable using SPS is due to intentional degradation of the GPS signal by the DoD (S/A). The PPS user (usually a DoD-approved user) can use a decryption device to achieve a point positional (3D) accuracy in the range of 10-16 m with a single-frequency receiver. Accuracies to less than a meter can be obtained from absolute GPS measurements when special equipment and post-processing techniques are employed.

b. Absolute point positioning with the carrier phase. By using broadcast ephemerides, the user is able to use pseudo-range values in real time to determine absolute point positions with an accuracy of between 3 m in the best of conditions and 80 m in the worst. By using a post-processed ephemerides (i.e., precise), the user can expect absolute point positions with an accuracy of near 1 m in the best of conditions and 40 m in the worst.

5-3. Pseudo-Ranging

When a GPS user performs a GPS navigation solution, only an approximate range, or pseudo-range, to selected satellites is measured. In order for the GPS user to determine his/her precise location, the known range to the satellite and the position of those satellites must be known. By pseudo-ranging, the GPS user measures an approximate distance between the antenna and the satellite by correlation of a satellite-transmitted code and a reference code created by the receiver, without any corrections for errors in synchronization between the clock of the transmitter and that of the receiver. The distance the signal has traveled is equal to the velocity of the transmission of the satellite multiplied by the elapsed time of transmission, with satellite signal velocity changes due to tropospheric and ionospheric conditions being considered. Refer to Figure 5-1 for an illustration of the pseudo-ranging concept. (See also paragraph 2-4*a,b*.)

a. The accuracy of the positioned point is a function of the range measurement accuracy and the geometry of the satellites, as reduced to spherical intersections with the earth's surface. A description of the geometrical magnification of uncertainty in a GPS-determined point position is Dilution of Precision (DOP), which is discussed in section 5-6*d*(2). Repeated and redundant range observations will generally improve range accuracy. However, the dilution of precision remains the same. In a static mode (meaning the GPS antenna stays stationary), range measurements to each satellite may be continuously remeasured over varying orbital locations of the satellite(s). The varying satellite orbits cause varying positional intersection geometry. In addition, simultaneous range observations to numerous satellites can be adjusted using weighting techniques based on the elevation and pseudo-range measurement reliability.

b. Four pseudo-range observations are needed to resolve a GPS 3D position. (Only three pseudo-range observations are needed for a 2D location.) In practice there are often more than four. This is due to the need to

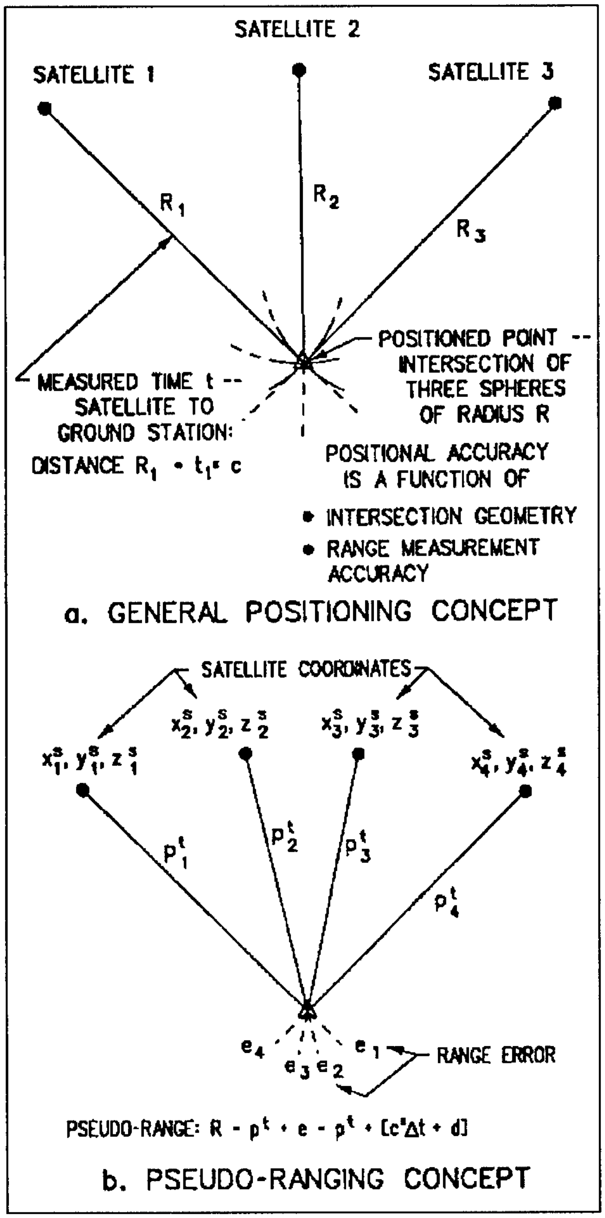


Figure 5-1. GPS satellite range measurement

resolve the clock biases Δt contained in both the satellite and ground-based receiver. Thus, in solving for the X-Y-Z coordinates of a point, a fourth unknown (i.e., clock bias) must also be included in the solution. The solution of the 3D position of a point is simply the solution of four pseudo-range observation equations containing four unknowns, i.e., X, Y, Z, and Δt.

c. A pseudo-range observation is equal to the true range from the satellite to the user ρ' plus delays due to satellite/receiver clock biases and other effects, as was shown in Figure 5-1.

$$R = p' + c(\Delta t) + d \tag{5-1}$$

where

R = observed pseudo-range

ρ' = true range to satellite (unknown)

c = velocity of propagation

Δt = clock biases (receiver and satellite)

d = propagation delays due to atmospheric conditions

These are usually estimated from models.

The true range ρ' is equal to the 3D coordinate difference between the satellite and user.

$$\rho' = \left[(X^s - X^u)^2 + (Y^s - Y^u)^2 + (Z^s - Z^u)^2\right]^{\frac{1}{2}} \tag{5-2}$$

where

X^s, Y^s, Z^s = known satellite coordinates from ephemeris data

X^u, Y^u, Z^u = unknown coordinates of user which are to be determined.

When four pseudo-ranges are observed, four equations are formed from Equations 5-1 and 5-2.

$$(R_1 - c\ \Delta t - d_1)^2 = \left(X_1^s - X^u\right)^2 + \left(Y_1^s - Y^u\right)^2 + \left(Z_1^s - Z^u\right)^2 \tag{5-3}$$

$$(R_2 - c\ \Delta t - d_2)^2 = \left(X_2^s - X^u\right)^2 + \left(Y_2^s - Y^u\right)^2 + \left(Z_2^s - Z^u\right)^2 \tag{5-4}$$

$$(R_3 - c\,\Delta t - d_3)^2 = \left(X_3^s - X^u\right)^2 + \left(Y_3^s - Y^u\right)^2 + \left(Z_3^s - Z^u\right)^2 \tag{5-5}$$

$$(R_4 - c\,\Delta t - d_4)^2 = \left(X_4^s - X^u\right)^2 + \left(Y_4^s - Y^u\right)^2 + \left(Z_4^s - Z^u\right)^2 \tag{5-6}$$

In these equations, the only unknowns are X^u, Y^u, Z^u, and Δt. Solving these equations at each GPS update yields the user's 3D position coordinates. Adding more pseudo-range observations provides redundancy to the solution. For instance, if seven satellites are simultaneously observed, seven equations are derived, and still only four unknowns result.

d. This solution is highly dependent on the accuracy of the known coordinates of each satellite (i.e., X^s, Y^s, and Z^s), the accuracy with which the atmospheric delays d can be estimated through modeling, and the accuracy of the resolution of the actual time measurement process performed in a GPS receiver (clock synchronization, signal processing, signal noise, etc.). As with any measurement process, repeated and long-term observations from a single point will enhance the overall positional reliability.

5-4. GPS Error Sources

There are numerous sources of measurement error that influence GPS performance. The sum of all systematic errors or biases contributing to the measurement error is referred to as range bias. The observed GPS range, without removal of biases, is referred to as a biased range or "pseudo-range." Principal contributors to the final range error that also contribute to overall GPS error are ephemeries error, satellite clock and electronics inaccuracies, tropospheric and ionospheric refraction, atmospheric absorption, receiver noise, and multipath effects. Other errors include those induced by DoD (Selective Availability (S/A) and Anti-Spoofing (A/S)). In addition to these major errors, GPS also contains random observation errors, such as unexplainable and unpredictable time variation. These errors are impossible to model and correct. The following paragraphs discuss errors associated with absolute GPS positioning modes. Many of these errors are either eliminated or significantly minimized when GPS is used in a differential mode. This is due to the same errors being common to both receivers during simultaneous observing sessions. For a more detailed analysis of these errors, consult one of the technical references listed in Appendix A.

a. Ephemeris errors and orbit perturbations. Satellite ephemeris errors are errors in the prediction of a satellite position which may then be transmitted to the user in the satellite data message. Ephemeris errors are satellite dependent and very difficult to completely correct and compensate for because the many forces acting on the predicted orbit of a satellite are difficult to measure directly. Because direct measurement of all forces acting on a satellite orbit is difficult, it is nearly impossible to accurately account or compensate for those error sources when modeling the orbit of a satellite. The previous accuracy levels stated are subject to performance of equipment and conditions. Ephemeris errors produce equal error shifts in calculated absolute point positions.

b. Clock stability. GPS relies very heavily on accurate time measurements. GPS satellites carry rubidium and cesium time standards that are usually accurate to 1 part in 10^{12} and 1 part in 10^{13}, respectively, while most receiver clocks are actuated by a quartz standard accurate to 1 part in 10^8. A time offset is the difference between the time as recorded by the satellite clock and that recorded by the receiver. Range error observed by the user as the result of time offsets between the satellite and receiver clock is a linear relationship and can be approximated by the following equation:

$$R_E = T_O * c \tag{5-7}$$

where

R_E = user equivalent range error

T_O = time offset

c = speed of light

(1) The following example shows the calculation of the user equivalent range error (UERE or UR).

T_O = 1 microsecond (μs) = 10^{-06} seconds (s)

c = 299,792,458 m/s

From Equation 5-7:

R_E = (10^{-06} seconds) * 299,792,458 m/s

= 299.79 m = 300 m user equivalent range error

(2) In general, unpredictable transient situations that produce high-order departures in clock time can be

ignored over short periods of time. Even though this may be the case, predictable time drift of the satellite clocks is closely monitored by the ground control stations. Through closely monitoring the time drift, the ground control stations are able to determine second-order polynomials which accurately model the time drift. The second-order polynomial determined by the ground control station to model the time drift is included in the broadcast message in an effort to keep this drift to within 1 millisecond (ms). The time synchronization between the GPS satellite clocks is kept to within 20 nsec (ns) through the broadcast clock corrections as determined by the ground control stations and the synchronization of GPS standard time to the Universal Time Coordinated (UTC) to within 100 ns. Random time drifts are unpredictable, thereby making them impossible to model.

(3) GPS receiver clock errors can be modeled in a manner similar to GPS satellite clock errors. In addition to modeling the satellite clock errors and in an effort to remove them, an additional satellite should be observed during operation to simply solve for an extra clock offset parameter along with the required coordinate parameters. This procedure is based on the assumption that the clock bias is independent at each measurement epoch. Rigorous estimation of the clock terms is more important for point positioning than for differential positioning. Many of the clock terms cancel when the position equations are formed from the observations during a differential survey session.

c. Ionospheric delays. GPS signals are electromagnetic signals and as such are nonlinearly dispersed and refracted when transmitted through a highly charged environment like the ionosphere. Dispersion and refraction of the GPS signal is referred to as an ionospheric range effect because dispersion and refraction of the signal result in an error in the GPS range value. Ionospheric range effects are frequency dependent.

(1) The error effect of ionosphere refraction on the GPS range values is dependent on sunspot activity, time of day, and satellite geometry. GPS operations conducted during periods of high sunspot activity or with satellites near the horizon produce range results with the most error. GPS operations conducted during periods of low sunspot activity, during the night, or with a satellite near the zenith produce range results with the least amount of ionospheric error.

(2) Resolution of ionospheric refraction can be accomplished by use of a dual-frequency receiver (a receiver that can simultaneously record both L1 and L2 frequency measurements). During a period of uninterrupted observation of the L1 and L2 signals, these signals can be continuously counted and differenced. The resultant difference reflects the variable effects of the ionosphere delay on the GPS signal. Single-frequency receivers used in an absolute and differential positioning mode typically rely on ionospheric models that model the effects of the ionosphere. Recent efforts have shown that significant ionospheric delay removal can be achieved using signal frequency receivers.

d. Tropospheric delays. GPS signals in the L-band level are not dispersed by the troposphere, but they are refracted. The tropospheric conditions causing refraction of the GPS signal can be modeled by measuring the dry and wet components. The dry component is best approximated by the following equation:

$$D_C = (2.27 * 0.001) * P_O \tag{5-8}$$

where

D_C = dry term range contribution in zenith direction in meters

P_O = surface pressure in millibar

(1) The following example shows the calculation of average atmospheric pressure P_O = 765 mb:

From Equation 5-8:

D_C = (2.27 * 0.001) * 765 mb

= 1.73655 m = 1.7 m, the dry term range error contribution in the zenith direction

(2) The wet component is considerably more difficult to approximate because its approximation is dependent not just on surface conditions, but also on the atmospheric conditions (water vapor content, temperature, altitude, and angle of the signal path above the horizon) along the entire GPS signal path. As this is the case, there has not been a well-correlated model that approximates the wet component.

e. Multipath. Multipath describes an error affecting positioning that occurs when the signal arrives at the receiver from more than one path. Multipath normally occurs near large reflective surfaces, such as a metal building or structure. GPS signals received as a result of

multipath give inaccurate GPS positions when processed. With the newer receiver and antenna designs and sound prior mission planning to eliminate possible causes of multipath, the effects of multipath as an error source can be minimized. Averaging of GPS signals over a period of time can also reduce the effects of multipath.

f. Receiver noise. Receiver noise includes a variety of errors associated with the ability of the GPS receiver to measure a finite time difference. These include signal processing, clock/signal synchronization and correlation methods, receiver resolution, signal noise, and others.

g. Selective Availability (S/A) and Anti-Spoofing (A/S). S/A purposely degrades the satellite signal to create position errors. This is done by dithering the satellite clock and offsetting the satellite orbits. The effects of S/A can be eliminated by using differential techniques discussed further in Chapter 6. A-S is implemented by interchanging the P-code with a classified Y-code. This denies users who do not possess an authorized decryption device. Manufacturers of civil GPS equipment have developed methods such as squaring or cross correlation in order to make use of the P-code when it is encrypted.

5-5. User Equivalent Range Error

The previous sources of errors or biases are principal contributors to overall GPS range error. This total error budget is often summarized as the UERE. As mentioned previously, they can be removed or at least effectively suppressed by developing models of their functional relationships in terms of various parameters that can be used as a corrective supplement for the basic GPS information. Differential techniques also eliminate many of these errors. Table 5-1 lists the more significant sources for errors and biases and correlates them to the segment source.

5-6. Absolute GPS Accuracies

The absolute range accuracies obtainable from GPS are largely dependent on which code (C/A or P) is used to determine positions. These range accuracies (i.e., UERE), when coupled with the geometrical relationships of the satellites during the position determination (i.e., DOP), result in a 3D confidence ellipsoid which depicts uncertainties in all three coordinates. Given the changing satellite geometry and other factors, GPS accuracy is time/location dependent. Error propagation techniques are used to define nominal accuracy statistics for a GPS user.

a. Root mean square error measures. Two-dimensional (2D) (horizontal) GPS positional accuracies are normally estimated using a root mean square (RMS) radial error statistic. A 1-σ RMS error equates to the radius of a circle in which the position has a 63 percent probability of falling. A circle of twice this radius (i.e., 2-σ RMS or 2DRMS) represents (approximately) a 97 percent positional probability circle. This 97 percent probability circle, or 2DRMS, is the most common positional accuracy statistic used in GPS surveying. In some instances, a 3DRMS or 99+ percent probability is used. This RMS error statistic is also related to the positional variance-covariance matrix. (Note that an RMS error statistic represents the radius of a circle and therefore is not preceded by a ± sign.)

Table 5-1
GPS Range Measurement Accuracy

		Absolute Positioning		
Segment Source	Error Source	C/A-code Pseudo-range, m	P-code Pseudo-range, m	Differential Positioning, m (P-code)
Space	Clock stability	3.0	3.0	Negligible
	Orbit perturbations	1.0	1.0	Negligible
	Other	0.5	0.5	Negligible
Control	Ephemeris predictions	4.2	4.2	Negligible
	Other	0.9	0.9	Negligible
User	Ionosphere	3.5	2.3	Negligible
	Troposphere	2.0	2.0	Negligible
	Receiver noise	1.5	1.5	1.5
	Multipath	1.2	1.2	1.2
	Other	0.5	0.5	0.5
1-σ UERE		±12.1	±6.5	±2.0

[a] Without S/A.

b. Probable error measures. 3D GPS accuracy measurements are most commonly expressed by Spherical Error Probable, or SEP. This measure represents the radius of a sphere with a 50 percent confidence or probability level. This spheroid radial measure only approximates the actual 3D ellipsoid representing the uncertainties in the geocentric coordinate system. In 2D horizontal positioning, a Circular Error Probable (CEP) statistic is commonly used, particularly in military targeting. CEP represents the radius of a circle containing a 50 percent probability of position confidence.

c. Accuracy comparisons. It is important that GPS accuracy measures clearly identify the statistic from which they are derived. A "100-m" or "3-m" accuracy statistic is meaningless unless it is identified as being either 1D, 2D, or 3D, along with the applicable probability level. For example, a PPS-16 m 3D accuracy is, by definition, SEP (i.e. 50 percent). This 16-m SEP equates to 28-m 3D 95 percent confidence spheroid, or when transformed to 2D accuracy, roughly 10 m CEP, 12 m RMS, 24 m 2DRMS, and 36 m 3DRMS. See Table 5-2 for further information on GPS measurement statistics. In addition, absolute GPS point positioning accuracies are defined relative to an earth-centered coordinate system/datum. This coordinate system will differ significantly from local project or construction datums. Nominal GPS accuracies may also be published as design or tolerance limits and accuracies achieved can differ significantly from these values.

d. Dilution of Precision (DOP). The final positional accuracy of a point determined using absolute GPS survey techniques is directly related to the geometric strength of the configuration of satellites observed during the survey session. GPS errors resulting from satellite configuration geometry can be expressed in terms of DOP. In mathematical terms, DOP is a scaler quantity used in an expression of a ratio of the positioning accuracy. It is the ratio of the standard deviation of one coordinate to the measurement accuracy. DOP represents the geometrical contribution of a certain scaler factor to the uncertainty (i.e., standard deviation) of a GPS measurement. DOP values are a function of the diagonal elements of the covariance matrices of the adjusted parameters of the observed GPS signal and are used in the point formulations and determinations (Figure 5-2).

(1) General. In a more practical sense, DOP is a scaler quantity of the contribution of the configuration of satellite constellation geometry to the GPS accuracy, in other words, a measure of the "strength" of the geometry of the satellite configuration. In general, the more satellites that can be observed and used in the final solution, the better the solution. Since DOP can be used as a measure of the geometrical strength, it can also be used to selectively choose four satellites in a particular constellation that will provide the best solution.

(2) Geometric dilution of precision (GDOP). The main form of DOP used in absolute GPS positioning is the geometric DOP (GDOP), which is a measure of accuracy in a 3D position and time. The relationship between final positional accuracy, actual range error, and GDOP can be expressed as follows:

$$\sigma_a = \sigma_R * \text{GDOP} \tag{5-9}$$

where

σ_a = final positional accuracy

σ_R = actual range error (UERE)

$$\text{GDOP} = \frac{\left[\sigma_E 2 + \sigma_N 2 + \sigma_u 2 + (c \cdot \delta_T)^2\right]^{\frac{1}{2}}}{\sigma_R} \tag{5-10}$$

where

σ_E = standard deviation in east value, m

σ_N = standard deviation in north value, m

σ_u = standard deviation in up direction, m

c = speed of light (299,792,458 m/s)

δ_T = standard deviation in time, s

σ_R = overall standard deviation in range, m, usually in the range of 6 m for P-code usage and 12 m for C/A-code usage

(3) Positional dilution of precision (PDOP). PDOP is a measure of the accuracy in 3D position, mathematically defined as:

$$\text{PDOP} = \frac{\left[\sigma_E 2 + \sigma_N 2 + \sigma_U 2\right]^{\frac{1}{2}}}{\sigma_R} \tag{5-11}$$

Table 5-2
Representative GPS Error Measurement Statistics for Absolute Point Positioning

Error Measure Statistic	**Probability %**	**Relative Distance ft(σ) (1)**	**GPS Precise Positioning Service m (2)**		**GPS Standard Positioning Service m (2)**	
Linear Measures			σ_N or σ_E	σ_U	σ_N or σ_E	σ_U
Probable error	50	0.6745 σ	± 4 m	± 9 m	± 24 m	± 53 m
Average error	57.51	0.7979 σ	± 5 m	± 11 m	± 28 m	± 62 m
1-sigma standard error/deviation (3)	68.27	1.00 σ	± 6.3 m	± 13.8 m	± 35.3 m	± 78 m
90% probability (map accuracy standard)	90	1.645 σ	± 10 m	± 23 m	± 58 m	± 128 m
95% probability/confidence	95	1.96 σ	± 12 m	± 27 m	± 69 m	± 153 m
2-sigma standard error/deviation	95.45	2.00 σ	**± 12.6 m**	**± 27.7 m**	**± 70.7 m**	**± 156 m**
99% probability/confidence	99	2.576 σ	± 16 m	± 36 m	± 91 m	± 201 m
3-sigma standard error (near certainty)	99.73	3.00 σ	± 19 m	± 42 m	± 106 m	± 234 m
Two-Dimensional Measures (4)			Circular Radius		Circular Radius	
1-sigma standard error circle (σ_c) (5)	39	1.00 σ_c	6 m		35 m	
Circular error probable (CEP) (6)	50	1.177 σ_c	7 m		42 m	
1-dev root mean square (1DRMS) (3)(7)	63	1.414 σ_c	9 m		50 m	
Circular map accuracy standard	90	2.146 σ_c	13 m		76 m	
95% 2D positional confidence circle	95	2.447 σ_c	15 m		86 m	
2-dev root mean square error (2DRMS) (8)	98+	2.83 σ_c	**17.8 m**		**100 m**	
99% 2D positional confidence circle	99	3.035 σ_c	19 m		107 m	
3.5-sigma circular near-certainty error	99.78	3.5 σ_c	22 m		123 m	
3-dev root mean square error (3DRMS)	99.9+	4.24 σ_c	27 m		150 m	
Three-Dimensional Measures			Spherical Radius		Spherical Radius	
1-σ spherical standard error (σ_s) (9)	19.9	1.00 σ_s	9 m		50 m	
Spherical error probable (SEP) (10)	50	1.54 σ_s	13.5 m		76.2 m	
Mean radial spherical error (MRSE) (11)	61	1.73 σ_s	16 m		93 m	
90% spherical accuracy standard	90	2.50 σ_s	22 m		124 m	
95% 3D confidence spheroid	95	2.70 σ_s	24 m		134 m	
99% 3D confidence spheroid	99	3.37 σ_s	30 m		167 m	
Spherical near-certainty error	99.89	4.00 σ_s	35 m		198 m	

Notes:

Most Commonly Used Statistics Shown in Bold Face Type.
Estimates not applicable to differential GPS positioning. Circular/Spherical error radii do not have ± signs.

Absolute positional accuracies are derived from GPS simulated user range errors/deviations and resultant geocentric coordinate (X-Y-Z) solution covariance matrix, as transformed to a local datum (N-E-U or φ-λ-h). GPS accuracy will vary with GDOP and other numerous factors at time(s) of observation. The 3D covariance matrix yields an error ellipsoid. Transformed ellipsoidal dimensions given (i.e., σ_N- σ_E- σ_U) are only average values observed under nominal GDOP conditions. Circular (2D) and spherical (3D) radial measures are only approximations to this ellipsoid, as are probability estimates.

(Continued)

Table 5-2
(Concluded)

(1) Valid for 2-D and 3-D only if $\sigma_N = \sigma_E = \sigma_U$. $(\sigma_{min}/\sigma_{max})$ generally must be ≥ 0.2. Relative distance used unless otherwise indicated.
(2) Representative accuracy based on 1990 FRNP simulations for PPS and SPS (FRNP estimates shown in bold), and that $\sigma_N \approx \sigma_E$. SPS may have significant short-term variations from these nominal values.
(3) Statistic used to define USACE hydrographic survey depth and positioning criteria.
(4) 1990 FRNP also proposes SPS maintain, at minimum, a 2D confidence of 300 m @ 99.99% probability.
(5) $\sigma_c \sim 0.5\ (\sigma_N + \sigma_E)$ -- approximates standard error ellipse.
(6) CEP $\sim 0.589\ (\sigma_N + \sigma_E) \approx 1.18\ \sigma_c$.
(7) 1DRMS $\sim (\sigma_N^2 + \sigma_E^2)^{1/2}$.
(8) 2DRMS $\sim 2\ (\sigma_N^2 + \sigma_E^2)^{1/2}$.
(9) $\sigma_s \sim 0.333\ (\sigma_N + \sigma_E + \sigma_U)$.
(10) SEP $\sim 0.513\ (\sigma_N + \sigma_E + \sigma_U)$.
(11) MRSE $\sim (\sigma_N^2 + \sigma_E^2 + \sigma_U^2)^{1/2}$.

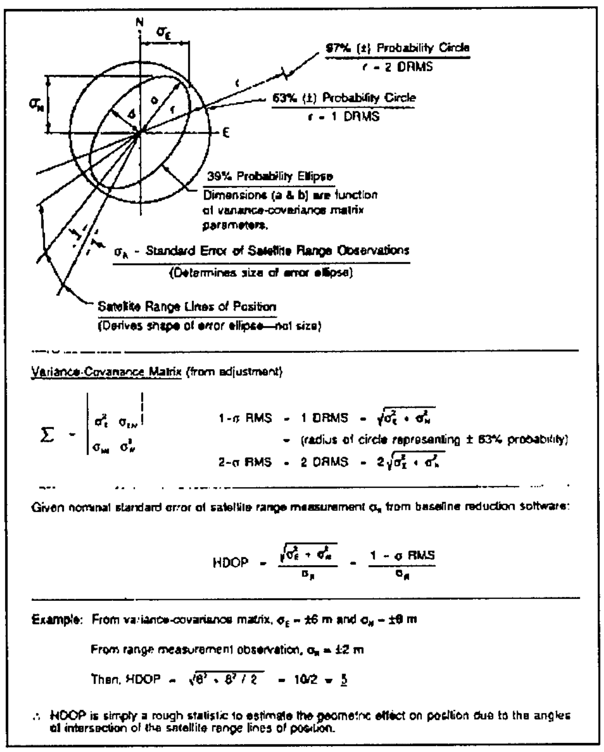


Figure 5-2. Dilution of Precision

where all variables are equivalent to those used in Equation 5-10.

(a) PDOP values are generally developed from satellite ephemerides prior to the conducting of a survey. When developed prior to a survey, PDOP can be used to determine the adequacy of a particular survey schedule. This is valid for rapid static or kinematic but is less valid for long duration static.

(b) The key to understanding PDOP is to remember that it represents position recovery at an instant in time and is not representative of a whole session of time. PDOP error is generally given in units of meters of error per 1-m error in the pseudo-range measurement (i.e., m/m). When using pseudo-range techniques, PDOP values in the range of 4-5 m/m are considered very good, while PDOP values greater than 10 m/m are considered very poor. For static surveys it is generally desirable to obtain GPS observations during a time of rapidly changing GDOP and/or PDOP.

(c) When the values of PDOP or GDOP are viewed over time, peak or high values (>10 m/m) can be associated with satellites in a constellation of poor geometry. The higher the PDOP or GDOP, the poorer the solution for that instant in time. This is critical in determining the acceptability of real-time navigation and photogrammetric solutions. Poor geometry can be the result of satellites being in the same plane, orbiting near each other, or at similar elevations.

(4) Horizontal dilution of precision (HDOP). HDOP is a measurement of the accuracy in 2D horizontal position, mathematically defined as:

$$\text{HDOP} = \frac{(\sigma_E^2 + \sigma_N^2)^{\frac{1}{2}}}{\sigma_R} \tag{5-12}$$

This HDOP statistic is most important in evaluating GPS surveys intended for horizontal control. The HDOP is basically the RMS error determined from the final variance-covariance matrix divided by the standard error of the range measurements. HDOP roughly indicates the effects of satellite range geometry on a resultant position.

(5) Vertical dilution of precision (VDOP). VDOP is a measurement of the accuracy in standard deviation in vertical height, mathematically defined as:

$$\mathrm{VDOP} = \frac{\sigma_u}{\sigma_R} \tag{5-13}$$

(6) Acceptable DOP values. Table 5-3 indicates generally accepted DOP values for a baseline solution.

(7) Additional material. Additional material regarding GPS positional accuracy may be found in the references listed in Appendix A.

Table 5-3
Acceptable DOP Values

GDOP and PDOP: Less than 10 m/m -- optimally 4-5 m/m.

In static GPS surveying, it is desirable to have a GDOP/PDOP that changes during the time of GPS survey session.

The lower the GDOP/PDOP, the better the instantaneous point position solution is.

HDOP and VDOP: 2 m/m for the best constellation of four satellites.

Chapter 6
GPS Relative Positioning Determination Concepts

6-1. General

Absolute positioning, as discussed earlier, will not provide the accuracies needed for most USACE control projects due to existing and induced errors. In order to eliminate these errors and obtain higher accuracies, GPS can be used in a relative positioning mode. The terms "relative" and "differential" used in this chapter and throughout this manual have similar meaning. "Relative" will be used when discussing one thing in relation to another. The term "differential" will be used when discussing the technique of positioning one thing in relation to another.

6-2. Differential (Relative) Positioning

Differential or relative positioning requires at least two receivers set up at two stations (usually one is known) to collect satellite data simultaneously in order to determine coordinate differences. This method will position the two stations relative to each other (hence the term "relative positioning") and can provide the accuracies required for basic land surveying and hydrographic surveying.

6-3. Differential Positioning (Code Pseudo-Range Tracking)

Differential positioning using code pseudo-ranges is performed similarly to that described in Chapter 5; however, some of the major uncertainties in Equations 5-1 through 5-6 are effectively eliminated or minimized. This pseudo-range process results in absolute coordinates of the user on the earth's surface. Errors in range are directly reflected in resultant coordinate errors. Differential positioning is not so concerned with the absolute position of the user but with the relative difference between two user positions, which are simultaneously observing the same satellites. Since errors in the satellite position (X^s, Y^s, and Z^s) and atmospheric delay estimates d are effectively the same (i.e., highly correlated) at both receiving stations, they cancel each other to a large extent.

a. For example, if the true pseudo-range distance from a "known" control point to a satellite is 100 m and the observed or measured pseudo-range distance was 92 m, then the pseudo-range error or correction is 8 m for that particular satellite. A pseudo-range correction or PRC can be generated for each satellite being observed. If a second receiver is observing at least four of the same satellites and is within a reasonable distance (300 km) it can use these PRCs to obtain a relative position to the "known" control point since the errors will be similar. Thus, the relative distance (i.e., coordinate difference) between the two stations is relatively accurate (i.e., within 0.5-5 m) regardless of the poor absolute coordinates. In effect, the GPS observed baseline vectors are no different from azimuth/distance observations. As with a total station, any type of initial coordinate reference can be input to start the survey.

b. The absolute GPS coordinates will not coincide with the user's local project datum coordinates (Figure 6-1). Since differential survey methods are concerned only with relative coordinate differences, disparities with a global reference system used by the NAVSTAR GPS are not significant for USACE purposes. Therefore, GPS coordinate differences can be applied to any type of local project reference datum (i.e., NAD 27, NAD 83, or any local project grid reference system).

c. Code pseudo-range tracking has primary application to real-time navigation systems where accuracies at the 0.5- to 5-m level are tolerable. Given these tolerances, engineering survey applications of code pseudo-range tracking GPS are limited, with two exceptions being hydrographic survey and dredge positioning. Specifications for real-time hydrographic code tracking systems are contained in EM 1110-2-1003. See Chapter 9 for further discussion on real-time code pseudo-range tracking applications.

6-4. Differential Positioning (Carrier Phase Tracking)

Differential positioning using carrier phase tracking uses a formulation of pseudo-ranges similar to those shown in Equations 5-1 through 5-6. The process becomes somewhat more complex when the carrier signals are tracked such that range changes are measured by phase resolution. In carrier phase tracking, an ambiguity factor is added to Equation 5-1 which must be resolved in order to obtain a derived range (see Figure 5-1). Methods for resolving this ambiguity (the number of unknown integer cycles) are described in Chapter 9. Carrier phase tracking provides for a more accurate range resolution due to the short wavelength (approximately 19 cm for L1 and 24 cm for L2) and the ability of a receiver to resolve the carrier phase down to about 2 mm. This method, therefore, has primary application to engineering, topographic, and geodetic surveying, and may be employed with either static

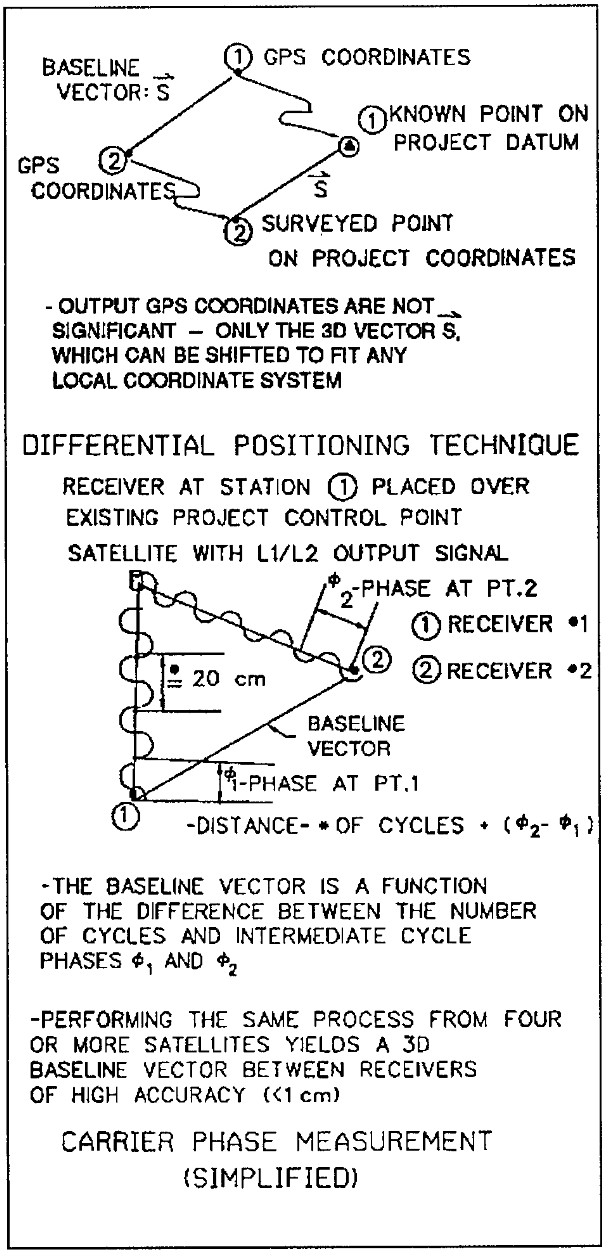


Figure 6-1. Differential positioning

or kinematic methods. There are several techniques which use the carrier phase in order to determine a station's position. These include static, rapid static, kinematic, stop and go kinematic, pseudo kinematic, and real-time kinematic (RTK) and on-the-fly (OTF) kinematic. The concepts of these techniques are explained below, but procedures can be found in Chapter 9. Table 6-1 lists these techniques, their associated accuracies, applications, and required components.

a. Static. Static surveying is the most widely used differential technique for control and geodetic surveying. It involves long observation times (1-2 hr, depending on number of visible satellites) in order to resolve the integer ambiguities between the satellite and the receiver. Accuracies in the subcentimeter range can be obtained from using the static method.

b. Rapid static. The concept of rapid static is to measure baselines and determine positions in the centimeter level with short observation times, 5-20 min. The observation time is dependent on the length of the baseline and number of visible satellites. Loss of lock, when moving from one station to the next, can also occur since each baseline is processed independent of each other.

c. Kinematic. Kinematic surveying, allows the user to rapidly and accurately measure baselines while moving from one point to the next. The data are collected and post-processed to obtain accurate positions to the centimeter level. This technique permits only partial loss of satellite lock during observation and requires a brief period of static initialization. The OTF technology, both real-time and post-processed, could eventually replace standard kinematic procedures at least for short baselines.

d. Stop and go kinematic. Stop and go kinematic involves collecting data for several minutes (1-2 min.) at each station after a period of initialization to gain the integers. This technique does not allow for loss of satellite lock during the survey. If loss of satellite lock does occur, a new period of initialization must take place. This method can be performed with two fixed or known stations in order to provide redundancy and improve accuracy.

e. Pseudo-kinematic. This technique is similar to standard kinematic procedures and static procedures combined. The differences are that there is no static initialization, longer period of time at each point (approximately 1-5 min), each point must be revisited after about an hour, and loss of satellite lock is acceptable. The positional accuracy is more than for kinematic or rapid static procedures, which makes it a less acceptable method for establishing baselines.

f. RTK and OTF carrier phase based positioning determination. The OTF/RTK positioning system uses

Table 6-1
Carrier Phase Tracking Techniques

Concept	Requirements	Applications	Accuracy
Static (Post-processing)	• L1 or L1/L2 GPS receiver • 386/486 computer for post-processing • 45 min to 1 hr minimum observation time[1]	• Control surveys (that require high accuracy)	• Subcentimeter level
Rapid Static (Post-processing)	• L1/L2 GPS receiver • 5-20 min observation time[1]	• Control surveys (that require medium to high accuracy)	• Subcentimeter level
Kinematic[2] (Post-processing)	• L1 GPS receiver with kinematic survey option • 386/486 computer for post-processing	• Continuous topo • Location surveys	• Centimeter level
Stop & Go Kinematic[2] (Post-processing)	• L1 GPS receiver • 386/486 computer for post-processing	• Medium accuracy control surveys	• Centimeter level
Pseudo Kinematic[2] (Post-processing)	• L1 GPS receiver • 386/486 computer for post-processing	• Medium accuracy control surveys	• Centimeter level
Real Time Kinematic/OTF Kinematic[3] (Real-time or post-processing)	For post-processing: • L1/L2 GPS receiver • 386/486 computer For real-time: • Internal or external processor (1- 386, 1- 486 computers w/dual com ports) • Min 4800 baud radio/modem data link set	• Real-time high accuracy hydro surveys • Location surveys • Medium accuracy control surveys • Photo control • Continuous topo	• Subdecimeter level

1. Dependent on satellite constellation and number of satellites in view.
2. Initialization period required and loss of satellite lock is not tolerated.
3. No static initialization necessary, integers gained while moving, and loss of satellite lock is tolerated.

GPS technology to allow the positioning to a subdecimeter in real time. This system determines the integer number of carrier wavelengths from the GPS antenna to the GPS satellite, transmitting them while in motion and without static initialization. The basic concept behind the OTF/RTK system is kinematic surveying without static initialization (integer initialization is performed while moving) and allows for loss of satellite lock. Other GPS techniques that can achieve this kind of accuracy require static initialization while the user is not moving and no loss of satellite lock while in motion.

6-5. Vertical Measurements with GPS

a. Elevation determination. **GPS is not recommended for Third-Order or higher vertical control surveys. It is recommended that it not be used as a substitute for standard differential leveling. It is, however, practical for small-scale topographic mapping or similar projects.**

b. Accuracy of GPS height differences. The height (*h*) component of GPS measurements is the weakest plane. This is due to the orbital geometry of the X-Y-Z position determination. Thus, GPS ellipsoidal height differences are usually less accurate than the horizontal components. Currently, GPS-derived elevation differences will not meet Third-Order standards as would be obtained using conventional spirit levels. Accordingly, GPS-derived elevations must be used with caution.

c. Topographic mapping with GPS. GPS positioning, whether operated in an absolute or differential positioning mode, can provide heights (or height differences) of surveyed points. The height h or height difference Δh obtained from GPS is in terms of height above or below

the WGS 84 ellipsoid. These ellipsoid heights are not the same as orthometric heights, or elevations, which would be obtained from conventional differential/spirit leveling. This distinction between ellipsoid heights and orthometric elevations is critical to many engineering and construction projects; thus, users of GPS must exercise extreme caution in applying GPS height determinations to USACE projects which are based on conventional orthometric elevations.

(1) GPS uses WGS 84 as the optimal mathematical model best describing the shape of the true earth at sea level based on an ellipsoid of revolution. The WGS 84 ellipsoid adheres very well to the shape of the earth in terms of horizontal coordinates but differs somewhat with the established mean sea level definition of orthometric height. The difference between ellipsoidal height, as derived by GPS, and conventional leveled (orthometric) heights is required over an entire project area to adjust GPS heights to orthometric elevations. NGS has developed geoid modeling software (GEOID90, GEOID91, and GEOID93) to be used to convert ellipsoidal heights to approximate orthometric elevations. These values should be used with extreme caution.

(2) Static or kinematic GPS survey techniques can be used effectively on a regional basis for the densification of low-accuracy vertical control for topographic mapping purposes. Existing benchmark data (orthometric heights) and corresponding GPS-derived ellipsoidal values for at least three stations in a small project area can be used in tandem in a minimally constrained adjustment program to reasonably model the geoid. More than three correlated stations are required for larger areas to ensure proper modeling of the geoidal undulations in the area. The model from the benchmark data and corresponding GPS data can then be used to derive the unknown orthometric heights of the remaining stations occupied during the GPS observation period.

(3) Procedures for constraining GPS observations to existing vertical control are detailed in Section 11 of Leick and Lambert (1990). Step-by-step vertical control planning, observation, and adjustment procedures employed by the NGS are described in some of the publications listed in Appendix A (see Zilkoski 1990a, 1990b; Zilkoski and Hothem 1989). These procedures are recommended should a USACE field activity utilize GPS to densify low-order vertical control relative to the orthometric datum.

6-6. Differential Error Sources

The error sources encountered in the position determination using differential GPS positioning techniques are the same as those outlined in Chapter 5. In addition to these error sources, the user must ensure that the receiver maintains lock on at least three satellites for 2D positioning and four satellites for 3D positioning. When loss of lock occurs, a cycle slip (a discontinuity of an integer number of cycles in the measured carrier beat phase as recorded by the receiver) may occur. In GPS absolute surveying, if lock is not maintained, positional results will not be formulated. In GPS static surveying, if lock is not maintained, positional results may be degraded, resulting in incorrect formulations. Sometimes, in GPS static surveying, if the observation period is long enough, post-processing software may be able to average out loss of lock and cycle slips over the duration of the observation period and formulate positional results that are adequate; if this is not the case, reoccupation of the stations may be required. In all differential surveying techniques, if loss of lock does occur on some of the satellites, data processing can continue easily if a minimum of four satellites have been tracked. Generally, the more satellites tracked by the receiver, the more insensitive the receiver is to loss of lock. In general, cycle slips can be repaired.

6-7. Differential GPS Accuracies

There are two levels of accuracies obtainable from GPS using differential techniques. The first level is based on pseudo-range formulations, while the other is based on carrier beat phase formulations.

a. Pseudo-range accuracies. Pseudo-range formulations can be developed from either the C/A-code or the more precise P-code. Pseudo-range accuracies are generally accepted to be 1 percent of the period between successive code epochs. Use of the P-code where successive epochs are 0.1 μs apart produces results that are around 1 percent of 0.1 μs or 1 ns. Multiplying this value by the speed of light gives a theoretical resultant range measurement of around 30 cm. If using pseudo-range formulations with the C/A-code, one can expect results 10 times less precise or a range measurement precision of around 3 m. Point positioning accuracy for a differential pseudo-range formulated solution is generally found to be in the range of 0.5-10 m. These accuracies are largely dependent on the type of GPS receiver being used.

b. Carrier beat phase formulations. Carrier beat phase formulations can be based on either the L1 or L2, or both carrier signals. Accuracies achievable using carrier beat phase measurement are generally accepted to be 1 percent of the wavelength. Using the L1 frequency where the wavelength is around 19 cm, one can expect a theoretical resultant range measurement that is 1 percent of 19 cm, or about 2 mm. The L2 carrier can only be used with receivers which employ a cross correlation, squaring, or some other technique to get around the effects of A/S.

(1) The final positional accuracy of a point determined using differential GPS survey techniques is directly related to the geometric strength of the configuration of satellites observed during the survey session. GPS errors resulting from satellite configuration geometry can be expressed in terms of DOP. Positional accuracy for a differential carrier beat phase formulated solution is generally found to be in the range of 1-10 mm.

(2) In addition to GDOP, PDOP, HDOP, and VDOP, the quality of the baselines produced by GPS differential techniques (static or kinematic) through carrier phase recovery can be defined by a quantity called relative DOP (RDOP). Multiplying the uncertainty of a double difference measurement by RDOP yields the relative position error for that solution. Values of RDOP are measured in meters of error in relative position per error of one cycle in the phase measurement (m/cycle). Knowledge of an RDOP or a value equivalent to it is extremely important to the confidence one assigns to a baseline recovery. Key to understanding RDOP is to remember that it represents position recovery over a whole session of time and is not representative of a position recovery at an instant in time. When carrier phase recovery techniques are used, RDOP values around 0.1 m/cycle are considered acceptable.

Chapter 7
GPS Survey Equipment

7-1. GPS Receiver Selection

Selection of the right GPS receiver for a particular project is critical to its success. To ensure success, selection must be based on a sound analysis of the following criteria: applications for which the receiver is to be used, accuracy requirements, power consumption requirements, operational environment, signal processing requirements, and cost. This chapter presents only a brief overview on GPS survey equipment and selection criteria. Prior to initiating procurement, USACE Commands are advised to consult the referenced guide specifications for procuring GPS equipment.

a. Receiver applications. Current USACE receiver applications include land-based, water-based, and airborne applications. Land applications include surveying, geodesy, resource mapping, navigation, survey control, boundary determination, deformation monitoring, and transportation. Water or marine applications include navigation and positioning of hydrographic surveys, dredges, and drill rigs. Airborne applications include navigation and positioning of photogrammetric-based mapping. Generally, the more applications a receiver must fulfill, the more it will cost. It is important for the receiver application to be defined in order to select the proper receiver and the necessary options.

b. Accuracy requirements. A firm definition of the accuracy requirements (e.g., point accuracy to 100 m, 50 m, 25 m, 5 m, 1 m, cm or mm) helps to further define procedure requirements (static or kinematic), signal reception requirements (whether use of C/A- or L1/L2 P-codes is appropriate), and type of measurement required (pseudo-range or carrier beat phase measurements). This is an important part in the receiver selection process.

c. Power requirements. The receiver power requirements are an important factor in the determination of receiver type. Receivers currently run on a variety of power sources from A/C to 12-volt car batteries or small camcorder batteries. A high end GPS receiver can operate 3 to 4 hr on a set of batteries, whereas a low end may operate 1 to 2 days on the same set.

d. Operational environment. The operational environment of the survey is also an important factor in the selection of antenna type and mount, receiver dimension and weight, and durability of design. For example, the harsher the environment (high temperature and humidity variability, dirty or muddy work area, etc.), the sturdier the receiver and mount must be. The operational environment will also affect the type of power source to be used.

e. Processing requirements. Operational procedures required before, during, and after an observation session are very manufacturer-dependent and should be thoughtfully considered before purchase of a receiver. Often, a receiver may be easy to operate in the field, requiring very little user interface, but a tremendous amount of time and effort may be required after the survey to download the data from the receiver and process it (i.e., post-processing software may be complicated, crude, or underdeveloped). Also, whether a post-processed or real-time solution is desired represents a variable that is critical in determining the type of receiver to use.

f. Cost. Cost is a major factor in determining the type of receiver the user can purchase. Receiver hardware and software costs are a function of development costs, competition among manufacturers, and product demand. Historically, costs for the acquisition of GPS equipment have steadily fallen to the current range of prices seen today. High end receivers are upwards of $35,000 down to a low end receiver of $500.

g. Data exchange formats. In receiver selection it is important to remember that there is currently no standard format for exchanging data from different types of GPS receivers. However, most GPS receiver data can be put into a common text format such as RINEX. Refer to paragraph 7-4 for further discussion on receiver formats.

h. USACE. For most USACE civil applications, continuous tracking, C/A-code, L1 tracking, multichannel (eight or more channels) receivers are adequate. Receivers with other features may be required for a particular application. For example, a dual frequency (L1/L2) receiver with the cross correlation, squaring, or some other technique during anti-spoofing is required for the OTF and rapid static surveying techniques.

7-2. Conventional GPS Receiver Types

There are two basic types of GPS receivers: code phase and carrier phase receivers. Within these types there are C/A- and P-code receivers, codeless receivers, single- and dual-frequency receivers, and receivers that use cross correlation or squaring or P-W techniques. Figure 7-1 shows common equipment required at a station.

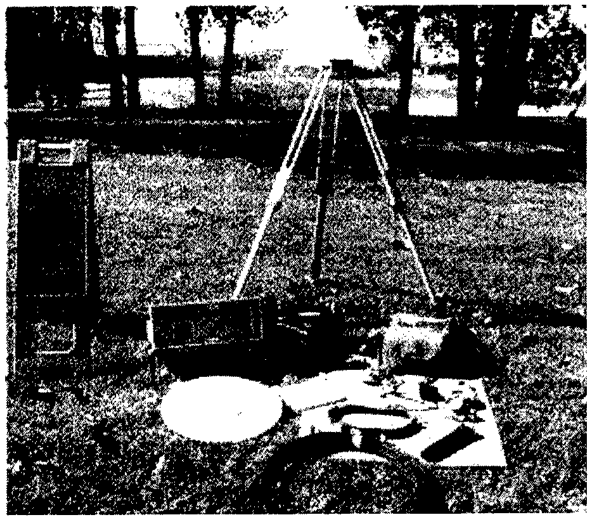


Figure 7-1. Common GPS equipment required at each setup

a. Code phase receivers. A code receiver is also called a "code correlating" receiver because it requires access to the satellite navigation message of the P- or C/A-code signal to function. This type of receiver relies on the satellite navigation message to provide an almanac for operation and signal processing. Because it uses the satellite navigation message, this type of receiver can produce real-time navigation data. Code receivers have "anywhere-fix" capability and, consequently, a quicker start-up time at survey commencement. An anywhere-fix receiver has the unique capability to begin calculations without being given an approximate location and time. A code receiver has anywhere-fix capability because it can synchronize itself with GPS time at a point with unknown coordinates once lock on the signals of four satellites has been obtained.

b. Carrier phase receivers. A carrier phase receiver utilizes the actual GPS signal itself to calculate a position. There are two general types of carrier phase receivers: (1) single frequency and (2) dual frequency.

(1) Single-frequency receivers. A single-frequency receiver tracks the L1 frequency signal. The single-frequency receiver generally has a lower price than the dual-frequency receiver because it has fewer components and is in greater demand. A single-frequency receiver can be used effectively to develop relative positions that are accurate over baselines of less than 50 km or where ionosphere effects can generally be ignored.

(2) Dual-frequency receivers. The dual-frequency receiver tracks both the L1 and L2 frequency signal. A dual-frequency receiver is generally more expensive than a single-frequency receiver. A dual-frequency receiver will more effectively resolve longer baselines of more than 50 km where ionosphere effects have a larger impact on calculations. Dual-frequency receivers eliminate almost all ionosphere effects by combining L1 and L2 observations. Most manufacturers of dual-frequency receivers utilize codeless techniques which allow the use of the L2 during anti-spoofing. These codeless techniques are squaring, cross-correlation, and P-W correlation.

(a) Squaring. Receivers which utilize the squaring technique are only able to obtain one-half of the signal wavelength on the L2 during anti-spoofing and have a high 30-dB loss.

(b) Cross correlation. Receivers that use this technique have a high 27-dB loss but are able to obtain the full wavelength on the L2 during anti-spoofing.

(c) P-W correlation. This method allows for both a low 14-dB loss and full wavelength on the L2 during anti-spoofing.

c. Military grade GPS receivers. The current military GPS receiver is the precise lightweight GPS receiver (PLGR), AN/PSN-11, which uses the course/acquisition (C/A), precise (P), or encrypted P(Y) codes. PLGR is designed to operate as a stand-alone unit and provide navigation information: position, velocity, and time. PLGR requires a crypto key to operate as a PPS receiver. A PPS receiver corrects for errors introduced by selective availability (S/A) and cannot be spoofed by imitated or retransmitted GPS signals, anti-spoofing (A/S). The accuracy is 16-m SEP when keyed. PLGR does not record code data because it was designed to be a navigation device, and P-code data are classified at time of reception. This also limits PLGR's ability to be used in differential GPS. PLGR can only be used in differential GPS when using C/A code and as a rover unit. However, C/A code differential GPS is not authorized by DoD for tactical military operations. If high accuracy surveys are required during a military conflict, PPS geodetic GPS receivers are available through commercial manufacturers. PLGRs or PPS receivers are the only authorized receivers to be used in a conflict area.

(1) Non-military DoD organizations that need PLGR accuracy for their positioning requirements can purchase

PLGR from the existing DoD contract through a memorandum of agreement with DoD.

(2) Commercial GPS receiver manufacturers produce hand-held, low cost PPS GPS receivers capable of 16-m SEP accuracy when keyed. These receivers may or may not have anti-spoofing capability and require the same crypto keys as PLGR.

7-3. Receiver Manufacturers

Up-to-date listings of manufacturers are contained in various surveying trade publications. Contact should be made directly with representatives of each firm to obtain current specifications, price, availability, material, or other related data on their products.

7-4. Other Equipment

There are several other relative miscellaneous equipment items that should be considered when making a GPS receiver selection. This equipment is discussed below.

a. Data link equipment for real-time positioning. The type of data link needed for real-time positioning should be capable of transmitting digital data. The specific type of data link will depend on the user's work area and environment. Most manufacturers of GPS equipment can supply or suggest a data link that can be used for real-time positioning. Depending on the type and wattage of the data link, a frequency authorization may have to take place in order to transmit digital data. Some radio and GPS manufacturers produce 1 W or less radios for transmission of digital data which do not require frequency authorization.

b. U.S. Coast Guard (USCG) radiobeacon receivers. The USCG provides a real-time pseudo-range corrections broadcast over low frequency (270-320 kHz marine band) from a radiobeacon transmitter tower. These towers exist in most if not all coastal areas including the Mississippi River and the Great Lakes regions. The range from each tower is approximately 120 to 300 km. These corrections can be received by using a radiobeacon receiver and antenna tuned to the nearest tower site. For further information on this system contact the USCG office in your district or the number listed in Appendix C.

c. Computer equipment. Most manufacturers of GPS receivers include computer specifications needed to run their downloading and post-processing software. Most software can be run on a 386-type computer with a math co-processor or on a 486-type computer.

d. Antenna types. There are three basic types of GPS antennas: ground plane antennas, no ground plane, and choke ring antennas. Both the ground plane and the choke rings are designed to reduce the effects of multipath on the antenna.

e. Associated survey equipment. There are several accessories needed along with a GPS receiver and antenna. These include tripods, tribrachs, and tribrach adapters to name a few. Fixed height (usually 2 m) poles can be used to eliminate the need to measure antenna heights. Most of the other equipment needed is similar to what is used in a conventional survey.

7-5. GPS Common Exchange Data Format

a. RINEX. Receiver INdependent EXchange (RINEX) format is an ASCII-type format which allows a user to combine data from different manufacturer's GPS receivers. Most GPS receiver manufacturers supply programs to convert raw GPS data into a RINEX format. However, one must be careful since there are different types of RINEX conversions. Currently, the NGS distributes software which converts several receivers' raw GPS data to RINEX. NGS will distribute this software free of charge to any government agency.

b. Real-time data transmission formats. There are two types of common data formats used most often during real-time surveying: (1) RTCM SC-104 v. 2 and (2) NMEA.

(1) Transmission of data between GPS receivers. The Radio Technical Commission for Maritime Services (RTCM) is the governing body for transmissions used for maritime services. The RTCM Special Committee 104 (SC-104) has defined the format for transmission of GPS corrections. The RTCM SC-104 standard was specifically developed to address meter-level positioning requirements. This current standard transmission standard for meter-level DGPS is the RTCM SC-104 v. 2.0. This standard allows various manufacturers' equipment to work together if it is used at both the reference and remote stations. It should be noted that not all manufacturers fully support the RTCM SC-104 v. 2.0 format, and careful consideration should be made to choose one that does. A committee was formed to address the means of a transmission format for centimeter-level DGPS. This committee proposed the RTCM SC-104 v. 2.1 format, which supports raw carrier phase data, raw pseudo-range data, and corrections for both. This will allow for correction of ionosphere and troposphere errors, with dual frequency measurements, to be applied at the receiving station. It is

deemed to be downward compatible with RTCM SC-104 v. 2.0, and therefore no special transmission considerations need to be made to use it.

(2) Transmission of data between a GPS receiver and a device. The *National Maritime Electronics Association (NMEA)* governs the format of output records (i.e., the positions at the remote end). The standard concerning the corrected GPS output records at the remote receiver is referred to as the *NMEA 0183 Data Sentencing Format.* The NMEA 0183 output records can be used as input to whatever system the GPS remote receiver is interfaced. For example, GPS receivers with an NMEA 0183 output can be used to provide the positional input for a hydrographic survey system or an Electronic Chart Display and Information System (ECDIS).

Chapter 8
Planning GPS Control Surveys

8-1. General

Using differential carrier phase GPS surveying to establish control for USACE civil and military projects requires operational and procedural specifications that are a project-specific function of the control being established. To accomplish these surveys in the most efficient and cost-effective manner, and to ensure that the required accuracy criteria are obtained, a detailed survey planning phase is essential. This chapter defines GPS survey design criteria and related observing specifications required to establish control for USACE military construction and civil works projects. Information on cost for GPS surveys can be found in Chapter 12, and information on using GPS for hydrographic surveys can be found in EM 1110-2-1003.

8-2. Required Project Control Accuracy

The first step in planning GPS control surveys is to determine the ultimate accuracy requirements. Survey accuracy requirements are a direct function of specific project functional needs, that is, the basic requirements needed to support planning, engineering design, maintenance, operations, construction, or real estate. This is true regardless of whether GPS or conventional surveying methods are employed to establish project control. Most USACE military and civil works engineering/construction activities require relative accuracies (i.e., accuracies between adjacent control points) ranging from 1:1,000 to 1:50,000, depending on the nature and scope of the project. Few USACE projects demand relative positional accuracies higher than the 1:50,000 level (Second-Order, Class I). Since the advent of GPS survey technology, there has been a tendency to specify higher accuracies than necessary. Specifying higher accuracy levels than those minimally required for the project can unnecessarily increase project costs.

a. Project functional requirements. Project functional requirements must include planned and future design, construction, and mapping activities. Specific control density and accuracy are designed from these functional requirements.

(1) Density of control within a given project is determined from factors such as planned construction, site plan mapping scales, master plan mapping scale, and dredging and hydrographic survey positioning requirements.

(2) The relative accuracy for project control is also determined based on mapping scales, design/construction needs, type of project, etc. Most site plan mapping for design purposes is performed and evaluated relative to American Society of Photogrammetry and Remote Sensing (ASPRS) standards. These standards apply to photogrammetric mapping, plane table mapping, total station mapping, etc. Network control must be of sufficient relative accuracy to enable hired-labor or contracted survey forces to reliably connect their supplemental mapping work.

b. Minimum accuracy requirements. Project control surveys shall be planned, designed, and executed to achieve the minimum accuracy demanded by the project's functional requirements. In order to most efficiently utilize USACE resources, control surveys shall not be designed or performed to achieve accuracy levels that exceed the project requirements. For instance, if a Third-Order, Class I accuracy standard (1:10,000) is required for offshore dredge/survey control on a navigation project, field survey criteria shall be designed to meet this minimum standard.

c. Achievable GPS accuracy. As stated previously, GPS survey methods are capable of providing significantly higher relative positional accuracies with only minimal field observations, as compared with conventional triangulation, trilateration, or EDM traverse. Although a GPS survey may be designed and performed to support lower accuracy project control requirements, the actual results could generally be several magnitudes better than the requirement. Although higher accuracy levels are relatively easily achievable with GPS, it is important to consider the ultimate use of the control on the project in planning and designing GPS control networks. Thus, GPS survey adequacy evaluations should be based on the project accuracy standards, not those theoretically obtainable with GPS.

(1) For instance, an adjustment of a pair of GPS-established points may indicate a relative distance accuracy of 1:800,000 between them. These two points may be subsequently used to set a dredging baseline using 1:2,500 construction survey methods; and from 100-ft-spaced stations on this baseline, cross sections are projected using 1:500 to 1:1,000 relative accuracy methods (typical hydrographic surveys). Had the GPS-observed baseline been accurate only to 1:20,000, such a closure would still have easily met the project's functional requirements.

(2) Likewise, in plane table topographic (site plan) mapping or photogrammetric mapping work, the difference between 1:20,000 and 1:800,000 relative accuracies is not perceptible at typical USACE mapping/construction scales (1:240 to 1:6,000), or ensuring supplemental compliance with ASPRS standards. In all cases of planimetric and topographic mapping work, the primary control network shall be of sufficient accuracy such that ASPRS standards can be met when site plan mapping data are derived from such points. For most large-scale military and civil mapping work performed by USACE, Third-Order relative accuracies are adequate to control planimetric and topographic features within the extent of a given sheet/map or construction site. On some projects covering large geographical areas (e.g., reservoirs, levee systems, installations), this Third-Order mapping control may need to be connected to/with a Second-Order (Class I or II) network to minimize scale distortions over longer reaches of the project.

(3) In densifying control for GIS databases, the functional accuracy of the GIS database must be kept in perspective with the survey control requirements. Performing 1:100,000 accuracy surveys for a GIS level containing 1-acre cell definitions would not be cost-effective; sufficient accuracy could be obtained by scaling relative coordinates from a U.S. Geological Survey (USGS) quadrangle map.

8-3. General GPS Network Design Factors

Some, but not all, of the factors to be considered in designing a GPS network (and subsequent observing procedure) should include the following:

a. Project size. The extent of the project will affect the GPS survey network shape. Many civil works navigation and flood control projects are relatively narrow in lateral extent but may extend for many miles longitudinally. Alternatively, military installations or reservoir/ recreation projects may project equally in length and breadth. The optimum GPS survey design will vary considerably for these different conditions.

b. Required density of control. The type of GPS survey scheme used will depend on the number and spacing of points to be established, which is a project-specific requirement. In addition, maximum baseline lengths between stations and/or existing control are also prescribed. Often, a combination of GPS and conventional survey densification will prove to be the most cost-effective approach.

c. Absolute GPS reference datums. Coordinate data for GPS baseline observations are referenced and reduced relative to WGS 84, an earth-centered (geocentric) coordinate system. This system is not directly referenced to but is closely related to, for all practical purposes, GRS 80 upon which North American Datum of 1983 (NAD 83) is related (for CONUS work). GPS data reduction and adjustment are normally performed using the WGS 84 earth-centered (geocentric) coordinate system (X-Y-Z), with baseline vector components (ΔX, ΔY, ΔZ) measured relative to this coordinate system. Although baseline vectors are measured relative to the WGS 84 system, for most USACE engineering and construction applications these data may be used in adjustments on NAD 27 (Clarke 1866). (See paragraphs 3-4 and 4-1.)

(1) If the external network being connected (and adjusted to) is the published NAD 83, the GPS baseline coordinates may be directly referenced on the GRS 80 ellipsoid since they are nearly equal. All supplemental control established is therefore referenced to the GRS 80/ NAD 83 coordinate system.

(2) If a GPS survey is connected to NAD 27 (SPCS 27) stations which were not adjusted to the NAD 83 datum, then these fixed points may be transformed to NAD 83 coordinates using USACE program CORPSCON (see EM 1110-1-1004) and the baseline reductions and adjustment performed relative to the GRS 80 ellipsoid. This method is recommended for USACE projects, only if resurveying is not a viable option.

(3) Alternatively, GPS baseline connections to NAD 27 (SPCS 27) project control may be reduced and adjusted directly on that datum with resultant coordinates on the NAD 27. Geocentric coordinates on the NAD 27 datum may be computed using the transformation algorithms given in Chapter 11. Refer also to EM 1110-1-1004 regarding state plane coordinate transforms between SPCS 27 and SPCS 83 grids. Conversions of final adjusted points on the NAD 27 datum to NAD 83 may also be performed using CORPSCON.

(4) Ellipsoid heights h referenced to the GRS 80 ellipsoid differ significantly from the orthometric elevations H on NGVD 29, NAVD 88, or dynamic/hydraulic elevations on the IGLD 55, IGLD 85. This difference (geoid separation, or N) can usually be ignored for horizontal control. This implies N is assumed to be zero and $h = H$ where the elevation may be measured, estimated, or scaled at the fixed point(s). See Chapter 6 for using GPS for vertical surveys.

(5) Datum systems other than NAD 27/NAD 83 will be used in OCONUS locations. Selected military operational requirements in CONUS may also require non-NAD datum references. It is recommended that GPS baselines be directly adjusted on the specific project datum.

d. Connections to existing control. For most static and kinematic GPS horizontal control work, at least two existing control points should be connected for referencing and adjusting a new GPS survey (Table 8-1). Existing points may be part of the NGRS or in-place project control which has been adequately used for years. Additional points may be connected if practical. In some instances, a single existing point may be used to generate spurred baseline vectors for supplemental construction control.

(1) Connections with existing project control. The first choice for referencing new GPS surveys is the existing project control. This is true for most surveying, not just GPS, and has considerable legal basis. Unless a newly authorized project is involved, long-established project control reference points should be used. If the project is currently on a local datum, then a supplemental tie to the NGRS should be considered as part of the project.

(2) Connections with NGRS. Connections with the NGRS (i.e., National Ocean Service/National Geodetic Survey control on NAD 83) are preferred where prudent and practical. As with conventional USACE surveying, such connections to the NGRS are not mandatory. In many instances, connections with the NGRS are difficult and may add undue cost to a project with limited resources. When existing project control is known to be of poor accuracy, then ties (and total readjustment) to the NGRS may be warranted. Sufficient project funds should have been programmed to cover the additional costs of these connections, including data submittal and review efforts if such work is intended to be included in the NGRS. (See paragraph 1-8*c* regarding advance programming requirements.)

(3) Mixed NGRS and project control connections. On existing projects, NGRS-referenced points should not be mixed with existing project control. This is especially important if existing project control was poorly connected with the older (NAD 27) NGRS, or if the method of this original connection is uncertain. Since NGRS control has been readjusted to NAD 83 (including subsequent high-precision HARNS readjustments of NAD 83) and most USACE project control has not, problems may result if these schemes are mixed indiscriminately. If a decision is made to establish and/or update control on an existing project, and connections with the NGRS (NAD 83/86) are required, then all existing project control points must be resurveyed and readjusted. Mixing different reference systems can result in different datums, with obvious adverse impacts on subsequent construction or boundary reference. It is far preferable to use "weak" existing (long-established) project control (on NAD 27 or whatever datum) for reference than to end up with a mixture of different systems or datums. See EM 1110-1-1004 for further discussion.

(4) Accuracy of connected reference control. Ideally, connections should be made to control of a higher order of accuracy than that intended for the project. In cases where NGRS control is readily available, this is usually the case. However, when only existing project control is available, connection and adjustment will have to be performed using that reference system, regardless of its accuracy. GPS baseline measurements should be performed over existing control to assess its accuracy and adequacy for adjustment, or to configure partially constrained adjustments.

(5) Connection constraints. Although Table 8-1 requires only a minimum of two existing stations to reliably connect GPS static and kinematic surveys, it may often be prudent to include additional NGRS and/or project points, especially if the existing network is of poor reliability. Adding additional points provides redundant checks on the surrounding network. This allows for the elimination of these points should the final constrained adjustment indicate a problem with one or more of the fixed points.

(a) Table 8-1 indicates the maximum allowable distance from the existing network that GPS baselines should extend.

(b) Federal Geodetic Control Subcommittee (FGCS) GPS standards (FGCC 1988) require connections to be spread over different quadrants relative to the survey project. Other GPS standards suggest an equilateral distribution of fixed control about the proposed survey area. These requirements are unnecessary for USACE work. The value shown in Table 8-1 (for Second-Order, Class I) is only suggested and not mandatory.

e. Location feasibility and field reconnaissance. A good advance reconnaissance of all marks within the project is crucial to the expedient and successful

Table 8-1
GPS Survey Design, Geometry, Connection, and Observing Criteria

Criterion	Classification Order			
	2nd, I	2nd, II	3rd, I	3rd, II
Relative accuracy				
ppm	20	50	100	200
1 part in	50k	20k	10k	5k
Required connections to existing horizontal control				
NGRS network		W/F/P		
Local project network		Yes		
Baseline observation check required over existing control	Yes	W/F/P	W/F/P	No
Number of connections with existing network (NGRS or local project control)				
Minimum	2	2	2	2
Optimum	3	3	2	2
New point spacing, m, not less than	1,000	500	200	100
Maximum distance from network to nearest control point in project, km	50	50	50	50
Minimum network control quadrant location (relative to project center)	2	N/R	N/R	N/R
Multiple station occupations (static GPS surveys)				
% Occupied three times	N/R	N/R	N/R	N/R
% Occupied two times	N/R	N/R	N/R	N/R
Repeat baseline observations (% of total baselines)	0	0	0	0
Master or fiducial stations required	W/F/P	No	No	No
Loop closure requirements:				
Maximum number of baselines/loop	10	20	20	20
Maximum loop length, km, not to exceed	100	200	N/R	N/R
Loop misclosure, ppm, not less than	20	50	100	200
Single spur baseline observations				
Allowed per order/class	No	No	Yes	Yes
Number of sessions/baseline	-	-	2	2
Required tie to NGRS	-	-	No	No
Field observing criteria -- static GPS surveys				
Required antenna phase height measurement per session	2	2	2	2
Meteorological observations required	No	No	No	No
Two frequency L1/L2 observations required:				
< 50-km lines	No	No	No	No
> 50-km lines	Yes	Yes	Yes	Yes

(Continued)

Table 8-1
(Concluded)

Criterion	Classification Order 2nd, I	2nd, II	3rd, I	3rd, II
Recommended minimum observing time (per session), min	60	45	30	30
Minimum number of sessions per GPS baseline	1	1	1	1
Satellite quadrants observed (minimum number)	3 W/F/P	N/R	N/R	N/R
Minimum obstruction angle above horizon, deg	15	15	15	15
Maximum HDOP/VDOP during session	N/R	N/R	N/R	N/R
Photograph and/or pencil rubbing required	A/R	No	No	No
Kinematic GPS surveying				
Allowable per survey class	Yes	Yes	Yes	Yes
Required tie to NGRS	W/F/P	W/F/P	No	No
Measurement time/baseline, min	(follow manufacturer's specifications) A/R			
Minimum number of reference points:	2	2	1-2	1
Preferred references	2	2	2	1
Maximum PDOP		15		
Minimum number of observations from each reference station	2	2	2	2
Adjustment and data submittal requirements				
Approximate adjustments allowed	Yes	Yes	Yes	Yes
Contract acceptance criteria				
Type of adjustment	Free (unconstrained)			
Evaluation statistic	Relative distance accuracies			
Error ellipse sizes	(not used as criteria)			
Histograms	(not used as criteria)			
Reject criteria				
Statistic	Normalized residual			
Standard	±3 * SEUW			
Optimum/nominal weighting				
Horizontal	± 5 + 2 ppm			
Vertical	± 10 + 2 ppm			
Optimum variance of unit weight	between 0.5 and 1.5			
GPS station/session data recording format	Bound field survey book or form			
Final station descriptions	Standard DA form			
FGCS/NGS Bluebook required	No			
Written project/adjustment report required	Yes			

Notes:

1. Abbreviations used in this table are explained as follows:
   W/F/P--Where feasible and practical.
   N/R--No requirement for this specification--usually indicates variance with provisional FGCC GPS specifications.
   A/R--As required in specific project instructions or manufacturer's operating manual.
   SEUW--Standard error of unit weight.
2. Classification orders refer to intended survey precision for USACE application, not necessarily FGCC standards designed to support national network densification.

completion of a GPS survey. The site reconnaissance should ideally be completed before the survey is started. The surveyor should also prepare a site sketch and brief description on how to reach the point since the individual performing the site reconnaissance may not be the surveyor that returns to occupy the known or unknown station.

(1) Project sketch. A project sketch should be developed before any site reconnaissance is performed. The sketch should be on a 7-1/2-min USGS quadrangle map or other suitable drawing. Drawing the sketch on the map will assist the planner in determination of site selections and travel distances between stations.

(2) Station descriptions and recovery notes. Station descriptions for all new monuments will be developed as the monumentation is performed. The format of these descriptions will follow that stated in EM 1110-1-1002. Recovery notes should be written for existing NGRS network stations and project control points, as detailed in EM 1110-1-1002. Estimated travel times to all stations should be included in the description. Include road travel time, walking time, and GPS receiver breakdown and setup time. These times can be estimated while performing the initial reconnaissance. A site sketch shall also be made on the description/recovery form. Examples of site reconnaissance reports are shown in Figures 8-1 and 8-2. A blank reconnaissance report form is included as Worksheet 8-1 (Figure 8-3), which may be used in lieu of a standard field survey book.

(3) Way point navigation. Way point navigation is an option on some receivers, allowing the user to enter geodetic position (usually latitude and longitude) of points of interest along a particular route the user may wish to follow. The GPS antenna, fastened to a vehicle or range pole, and receiver can then provide the user with navigational information. The navigational information may include the distance and bearing to the point of destination (stored in the receiver), the estimated time to destination, and the speed and course of the user. The resultant message produced can then be used to guide the user to the point of interest. Way point navigation is an option that, besides providing navigation information, may be helpful in the recovery of control stations which do not have descriptions. If the user has the capability of real-time code phase positioning, the way point navigational accuracy can be in the range of 0.5 - 10 m.

(4) Site obstruction/visibility sketches. The individual performing the site reconnaissance should record the azimuth and vertical angle of all obstructions. The azimuths and vertical angles should be determined with a compass and inclinometer. Because obstructions such as trees and buildings cause the GPS signal transmitted from the GPS satellite to be blocked, the type of obstruction is also an important item to be recorded, see Figure 8-2. The type of obstruction is also important to determine if multipath might cause a problem. Multipath is caused by the reflection of the GPS signal by a nearby object producing a false signal at the GPS antenna. Buildings with reflective surfaces, chain-link fences, and antenna arrays are objects that may cause multipath. The site obstruction data are needed to determine if the survey site is suitable for GPS surveying. Obstruction data should be plotted on a Station Visibility Diagram, as shown in Figure 8-4. (A blank copy of this form is provided as Worksheet 8-2 (Figure 8-5).) GPS surveying does require that all stations have an unobstructed view 15 deg above the horizon, and satellites below 10 deg should not be observed.

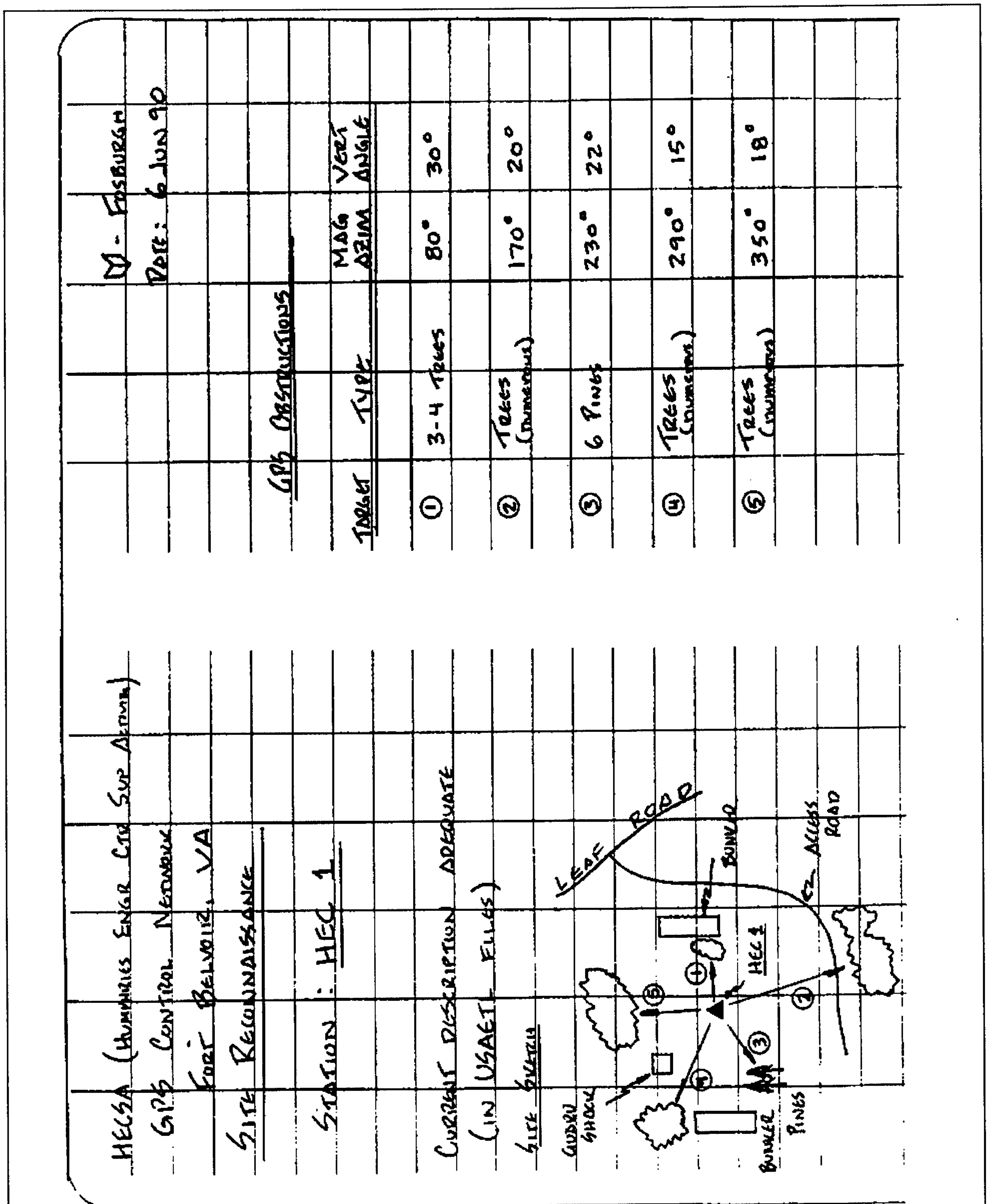
(5) Suitability for kinematic observations. Clear, obstruction-free projects may be suitable for kinematic GPS surveys as opposed to static. The use of kinematic observations will increase productivity by a factor of 5 to 10 over static methods, while still providing adequate accuracy levels. On many projects, a mixture between both static and kinematic GPS observations may prove to be most cost-effective.

(6) Monumentation. All monumentation should follow the guidelines of EM 1110-1-1002.

(7) On-site physical restrictions. The degree of difficulty in occupying points due to such factors as travel times, site access, multipath effects, and satellite visibility should be anticipated. The need for redundant observations, should reobservations be required, must also be considered.

(8) Checks for disturbed existing control. Additional GPS baselines may need to be observed between existing NGRS/project control to verify their accuracy and/or stability.

(9) Satellite visibility limitations. For most of the Continental United States, there are at least four to five satellites in view at all times. However, some areas may have less during times of satellite maintenance or unhealthy satellites. Satellite visibility charts of the GPS satellite constellation play a major part in optimizing network configurations and observation schedules.



HECSA (Humphries Engr Ctr Sup Activity)
GPS Control Network
Fort Belvoir, VA
Site Reconnaissance

Station: HEC 1

Current description adequate
(in USAETL files)

Site Sketch

- Fosburgh
Date: 6 Jun 90

GPS Obstructions

Target	Type	Mag Azim	Vert Angle
1	3-4 Trees	80°	30°
2	Trees (numerous)	170°	20°
3	6 Pines	230°	22°
4	Trees (numerous)	290°	15°
5	Trees (numerous)	350°	18°

Figure 8-1. Sample site reconnaissance sketch

SITE RECONNAISSANCE/REPORT ON CONDITION OF SURVEY MARK

Project for Which Reconnaissance was Performed DWORSHAK DAM

Station Name OROFINO Year Established 1933

State Code ID County POTTER Map Scale 1:24,000

Organization's Mark C & GS Map Sheet CLEARWATER

Search Performed By K. SMITH Date 4/12/89

Organization WALLA WALLA DISTRICT

Exact Stamping OROFINO 1933 Condition GOOD

Please report on the thoroughness of the search in case the mark was not recovered. Suggest changes in description, need for repairing or moving the mark, or other pertinent facts. Record letters and numbers found stamped in (not cast in) the mark.

THE MARK WAS RECOVERED USING THE 1970 DESCRIPTION. ADDITIONAL DESCRIPTIVED DATA: THE MARK IS 89.7' W OF PP #6342, 62.4' NE OF AN 18" MAPLE, 42.0' S OF A 10" SPRUCE AND 2' E OF AN ORANGE WITNESS POST.
RECOVERED REFERENCE MARK OROFINO NO. 1 1933 GOOD
" " " OROFINO NO. 3 1970 GOOD

****

TRAVEL TIME BY 2-WHEEL DRIVE VEHICLE FROM CLEARWATER IS APPROX. 15 MINUTES.

SKETCH

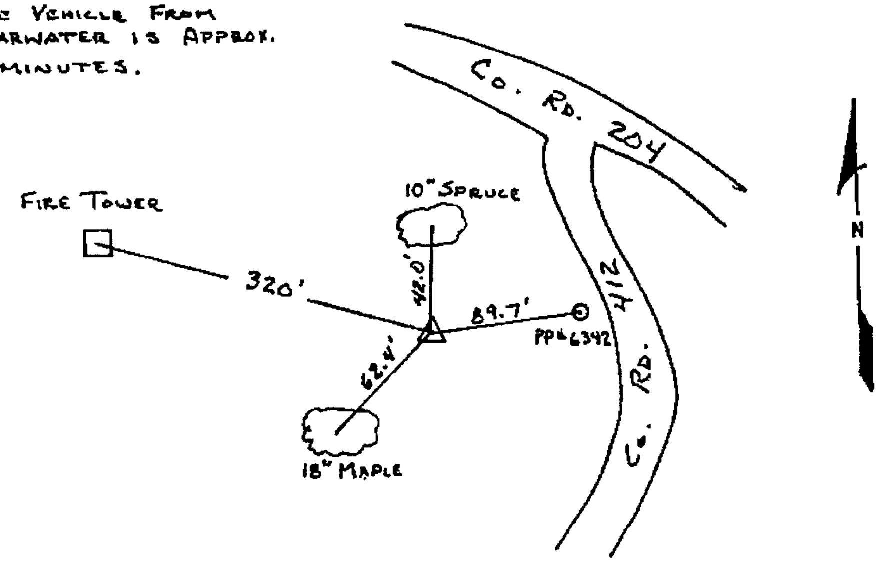


Figure 8-2. Reconnaissance report on condition of survey

SITE RECONNAISSANCE/REPORT ON CONDITION OF SURVEY MARK

Project for Which Reconnaissance was Performed ______________________

Station Name ______________________ Year Established ______

State Code ____ County ______________ Map Scale __________

Organization's Mark ______________ Map Sheet __________

Search Performed By ______________ Date __________

Organization ______________________________

Exact Stamping ______________ Condition __________

Please report on the thoroughness of the search in case the mark was not recovered. Suggest changes in description, need for repairing or moving the mark, or other pertinent facts. Record letters and numbers found stamped in (not cast in) the mark.

____
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SKETCH

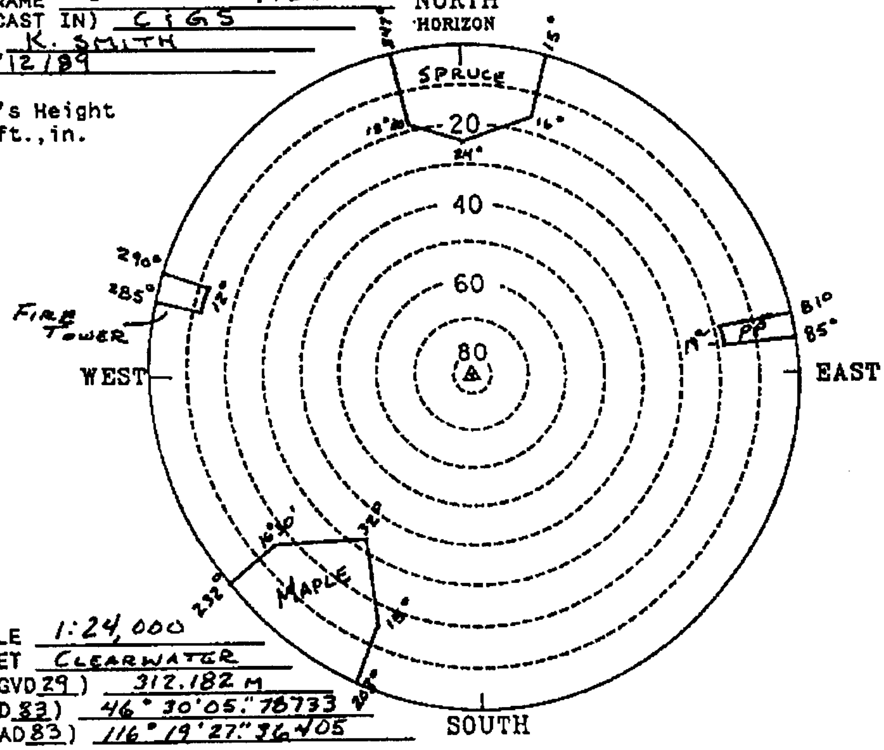
N

Figure 8-3. Worksheet 8-1, Site Reconnaissance Report form

STATION VISIBILITY DIAGRAM

STATION NAME OROFINO 1933
AGENCY (CAST IN) C & GS
OBSERVER K. SMITH
DATE 4/12/89

Observer's Height
5' 10" ft.,in.



MAP SCALE 1:24,000
MAP SHEET CLEARWATER
ELEV (NGVD 29) 312.182 M
LAT (NAD 83) 46° 30' 05." 78733 N
LONG (NAD 83) 116° 19' 27." 36405

Indicate the horizontal and vertical limits of all objects obstucting veiw of the sky exceeding 15 degrees above the horizon.

NO.	AZIMUTH	VERT ANGLE	DESCRIPTION	NO.	AZIMUTH	VERT ANGLE	DESCRIPTION
1	347°00'	18° 30'	EDGE SPRUCE	11			
2	358°30'	24°00'	PEAK SPRUCE	12			
3	15°00'	16°00'	EDGE SPRUCE	13			
4	81°00'	19° 00'	N/EDGE PP	14			
5	85°30'	19° 00'	S/EDGE PP	15			
6	203°00'	15° 00'	EDGE MAPLE	16			
7	215°30'	32° 00'	PEAK MAPLE	17			
8	232°00'	16° 30'	EDGE MAPLE	18			
9				19			
10				20			

Indicate distance, direction, frequency and power of known RF sources. Indicate distance, horizontal and vertical limits of any object in the vicinity that may cause radio signals to be reflected (multipath).

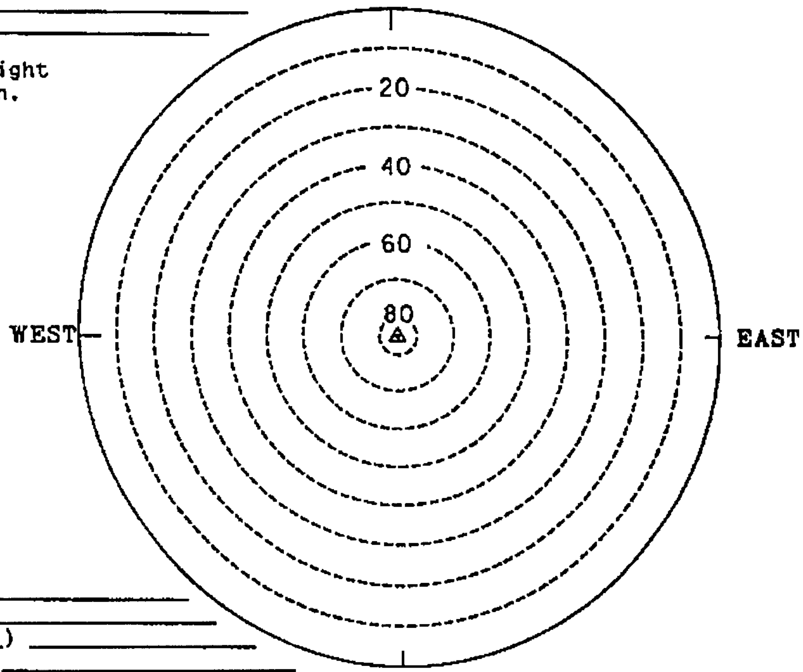
1. 320' 285° TO 290° VERT ∡ 12° FIRE TOWER
2. (DUE TO DISTANCE FROM STATION & LOW ELEVATION ANGLE, THIS IS
3. PROBABLY NOT A THREAT OF CAUSING MULTIPATH)

Figure 8-4. Sample station visibility diagram

STATION VISIBILITY DIAGRAM

STATION NAME ____________________
AGENCY (CAST IN) ____________________
OBSERVER ____________________
DATE ____________________

Observer's Height
______ ft.,in.



MAP SCALE ____________________
MAP SHEET ____________________
ELEV (NGVD___) ____________________
LAT (NAD___) ____________________
LONG (NAD___) ____________________

Indicate the horizontal and vertical limits of all objects obstucting veiw of the sky exceeding 15 degrees above the horizon.

NO.	AZIMUTH	VERT ANGLE	DESCRIPTION	NO.	AZIMUTH	VERT ANGLE	DESCRIPTION
1				11			
2				12			
3				13			
4				14			
5				15			
6				16			
7				17			
8				18			
9				19			
10				20			

Indicate distance, direction, frequency, and power of known RF sources. Indicate distance, horizontal and vertical limits of any object in the vicinity that *may* cause radio signals to be reflected (multipath).

1. ____________________
2. ____________________
3. ____________________

Figure 8-5. Worksheet 8-2, Station Visibility Diagram

(10) Station intervisibility requirements. Project specifications may dictate station intervisibility for azimuth reference. This may constrain minimum station spacing.

f. Multiple/repeat baseline connections. Table 8-1 lists recommended criteria for baseline connections between stations, repeat baseline observations, and multiple station occupations. Many of these standards were developed by FGCS for performing high-precision geodetic control surveys such that extensive redundancy will result from the collected data. Since the purpose of these geodetic densification surveys is markedly different from USACE control densification, the need for such high observational redundancy is also different. Adding redundant baseline/station occupations may prove prudent on some remote projects where accessibility is difficult.

g. Loop requirements. Loops (i.e., traverses) provide the mechanism for performing field data validation as well as final adjustment accuracy analysis. Since loops of GPS baselines are comparable to traditional EDM/taped traverse routes, misclosures and adjustments can be handled similarly. Most GPS survey nets (static or kinematic) end up with one or more interconnecting loops that are either internal from a single fixed point or external through two or more fixed network points. Loops should be closed off at the spacing indicated in Table 8-1. Loop closures should meet the criteria specified in Table 8-1, based on the total loop length. See also Chapter 10 for additional GPS loop closure checks.

(1) GPS control surveys may be conducted by forming loops between two or more existing points, with adequate cross-connections where feasible. Such alignment procedures are usually most practical on civil works navigation projects which typically require control to be established along a linear path, e.g., river or canal embankments, levees, beach renourishment projects, and jetties.

(2) Loops should be formed every 10 to 20 baselines, preferably closing on existing control.

(3) Connections to existing control should be made as opportunities exist and/or as often as practical.

(4) When establishing control over relatively large military installations, civil recreation projects, flood control projects, and the like, a series of redundant baselines forming interconnecting loops is usually recommended. When densifying Second- and Third-Order control for site plan design and construction, extensive cross-connecting loop and network configurations recommended by the FGCS for geodetic surveying are not necessary.

(5) On all projects, maximum use of combined static and kinematic GPS observations should be considered, both of which may be configured to form pseudo-traverse loops for subsequent field data validation and final adjustment.

8-4. GPS Network Design and Layout

A wide variety of survey configuration methods may be used to densify project control using GPS survey techniques. Unlike conventional triangulation, trilateration, and EDM traverse surveying, the shape, or geometry, of the GPS network design is not as significant. The following guidelines for planning and designing proposed GPS surveys are intended to support lower order (Second-Order, Class I, or 1:50,000 or less accuracy) control surveys applicable to USACE civil works and military construction activities. An exception to this would be GPS surveys supporting structural deformation monitoring projects where relative accuracies at the centimeter level or better are required over a small project area.

a. Newly established GPS control may or may not be incorporated into the NGRS, depending on the adequacy of the connection to the existing NGRS network, or whether it was tied only internally to existing project control.

b. Of paramount importance in developing a network design is to obtain the most economical coverage within the prescribed project accuracy requirements. The optimum network design, therefore, provides a minimum amount of baseline/loop redundancy without an unnecessary amount of "over-observation." Obtaining this optimum design (cost versus accuracy) is difficult and constantly changing due to evolving GPS technology and satellite coverage.

c. GPS survey layout schemes. The planning of a GPS survey scheme is similar to that for conventional triangulation or traversing. The type of survey design adopted is dependent on the GPS technique employed and the requirements of the user.

(1) GPS networking. A GPS network is proposed when established survey control is to be used in precise network densification (1:50,000-1:100,000). For lower order work (i.e., less than 1:50,000), elaborate network schemes are unnecessary and less work-intensive GPS

survey extension methods may be used. When the networking method is selected, the surveyor should devise a survey network that is geometrically sound. Triangles that are weak geometrically should be avoided. The networking method is practical only with static, pseudo-kinematic, and kinematic survey techniques. Figure 8-6 shows an example of a step-by-step method to build a GPS survey network.

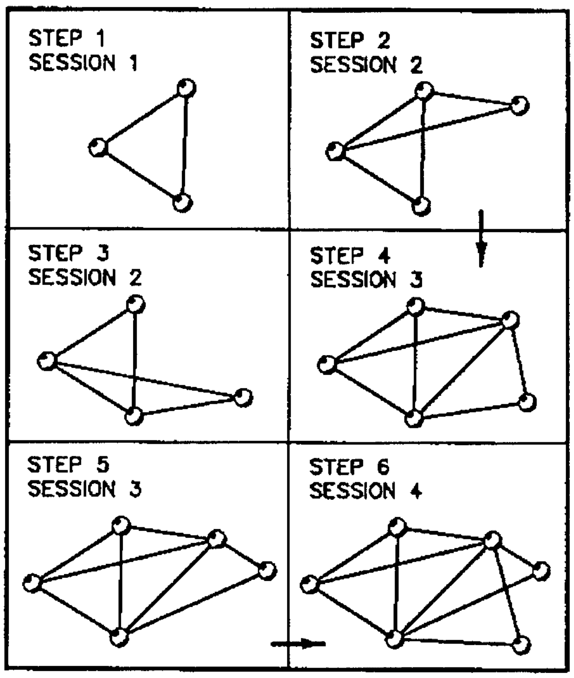


Figure 8-6. GPS network design

(2) GPS traversing. Traversing is the method of choice when the user has only two or three receivers and required accuracies are 1:5,000-1:50,000. Traversing with GPS is done similar to conventional methods. Open-end traverses are not recommended when 1:5,000 accuracies or greater are required. Since GPS does not provide sufficient point positioning accuracies, the surveyor must have a minimum of one fixed (or known) control point, although three are preferred. A fixed control point is a station with known latitude-longitude-height or easting-northing-height. This point may or may not be part of the NGRS. If only one control point is used and the station does not have a known height, the user will be unable to position the unknown stations. When performing a loop traverse, the surveyor should observe a check angle or check azimuth using conventional survey techniques to determine if the known station has been disturbed. If azimuth targets are not visible, and a check angle cannot be observed, a closed traverse involving one or more control points is recommended. Again, a check angle or check azimuth should be observed from the starting control station. If a check angle is not performed, the survey can still be completed. However, if the survey does not meet specified closure requirements, the surveyor will be unable to assess what control point may be in error. If a check angle or check azimuth cannot be observed, a third control point should be tied into the traverse (Figure 8-7). This will aid in determining the cause of misclosure.

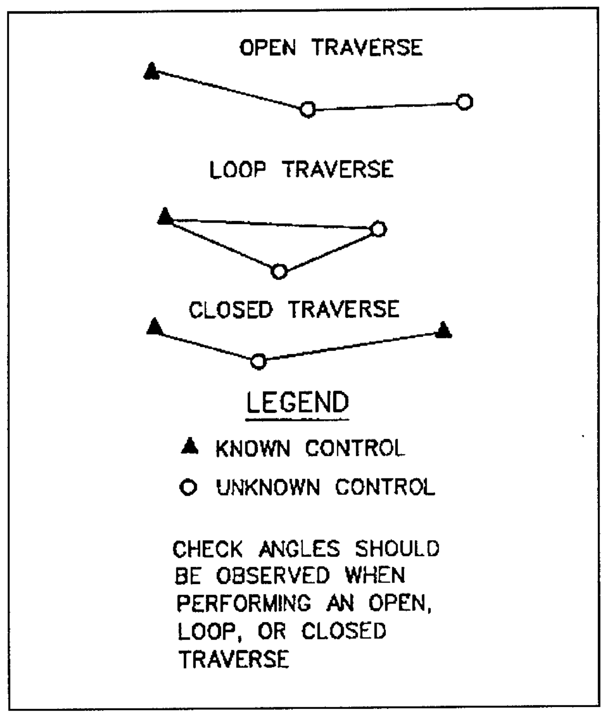


Figure 8-7. GPS traversing schemes

(3) GPS spur shots. Spurs are an acceptable method when the user has only two receivers or only a few control points are to be established. Spur lines should be observed twice during two independent observing sessions. Once the first session is completed, the receivers at each station should be turned off and the tripod elevations changed. This procedure is similar to performing a forward and backward level line. It is important that the tripods be moved in elevation and replumbed over the control station between sessions. If this step is not implemented, the two baselines cannot be considered independent. Figure 8-8 shows an example of a spur line. Spurs are most applicable to static survey and relative positioning (code phase) techniques.

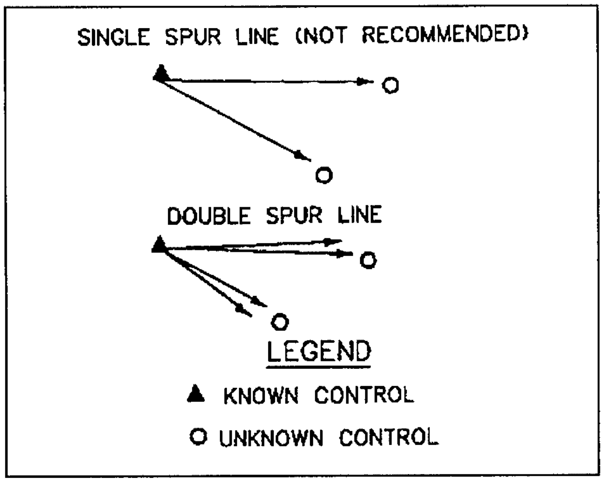


Figure 8-8. GPS spur line

8-5. GPS Techniques Needed for Survey

After a GPS network has been designed and laid out, a GPS survey method or technique needs to be considered. The concepts for each method were discussed in Chapter 6 and the procedures are discussed in Chapter 9. The most efficient method should be chosen in order to minimize time and cost while meeting the accuracy requirements of a given survey project. Once a technique is chosen, the following can be set up: equipment requirements, observation schedules, and sessions designations and planning functions.

a. General equipment requirements. The type of GPS instrumentation used on a project depends on the accuracy requirements of the project, GPS survey technique, project size, and economics. Most USACE projects can be completed using a single-frequency receiver. Dual-frequency receivers are recommended as baseline lengths approach or exceed 50 km. This length may also vary depending on the amount of solar activity during the observation period. Using a dual-frequency receiver permits the user to solve for possible ionospheric and tropospheric delays which can occur as the signal travels from the satellite to the receiver antenna.

(1) Number of GPS receivers. The minimum number of receivers required to perform a differential GPS survey is two. The actual number used on a project will depend on the project size and number of available instruments/operators. Using more than two receivers will often increase productivity and allow for more efficient field observations. For some kinematic applications, two reference (set at known points) receivers and at least one rover are recommended.

(2) Personnel. Personnel requirements are also project dependent. Most GPS equipment is compact and light weight and only requires one person per station setup. However, some cases where a station is not easily accessible or requires additional power for a data link, two individuals may be required.

(3) Transportation. One vehicle is normally required for each GPS receiver used on a project. This vehicle should be equipped to handle the physical conditions that may be encountered while performing the field observations. In most cases, a two-wheel-drive vehicle should be adequate for performing all field observations. If adverse site conditions exist, a four-wheel-drive vehicle may be required. Adequate and reliable transportation is important when the observation schedule requires moving from one station to another between observation sessions.

(4) Auxiliary equipment. Adequate power should be available for all equipment (receivers, computers, lights, etc.) that will be used during the observations. Computers (386-based recommended), software, and data storage devices (floppy disks and/or cassette tapes) should be available for onsite field data reduction use. Other equipment required for conduct of a GPS survey should include tripods, tribrachs, measuring tapes, flagging, flashlights, tools, equipment cables, compass, and inclinometer. If real-time positioning is required, then a data link is also needed.

b. Observation schedules. Planning a GPS survey requires that the surveyor determine when satellites will be visible for the given survey area; therefore, the first step in determining observation schedules is to plot a satellite visibility plot for the project area. Even when the GPS becomes fully operational, full 24-hr coverage of at least four satellites may not be available in all areas.

(1) Most GPS manufacturers have software packages which at least predict satellite rise and set times. An excellent satellite plot will have the following essential information: satellite azimuths, elevations, set and rise times, and satellite PDOPs for the desired survey area. Satellite ephemeris data are generally required as input for the prediction software.

(2) To obtain broadcast ephemeris information, a GPS receiver collects data during a satellite window. The receiver antenna does not have to be located over a

known point when collecting a broadcast ephemeris. The data are then downloaded to a personal computer where they are used as input into the software prediction program. Besides ephemeris data for the software, the user is generally required to enter approximate latitude and longitude (usually scaled from a topographic map) and time offset from UTC for the survey area.

(3) From the satellite plot, the user can determine the best time to perform a successful GPS survey by taking advantage of the best combination of satellite azimuths, elevations, and PDOPs as determined by the satellite visibility plot for the desired survey area (for further information on favorable PDOP values, refer to Chapter 5). The number of sessions and/or stations per day depends on satellite visibility, travel times between stations, and the final accuracy of the survey. Often, a receiver is required to occupy a station for more than one session per day.

(4) A satellite polar plot (Figure 8-9), a satellite azimuth and elevation table (Figure 8-10), and a PDOP versus time plot (Figure 8-11) may be run prior to site reconnaissance. The output files created by the satellite prediction software are used in determining if a site is suitable for GPS surveying.

(5) Determination of session times is based mainly on the satellite visibility plan with the following factors taken into consideration: time required to permit safe travel between survey sites; time to set up and take down the equipment before and after the survey; time of survey; and possible time loss due to unforeseeable problems or complications. Station occupation during each session should be designed to minimize travel time in order to maximize the overall efficiency of the survey.

c. Session designations and planning functions. A survey session in GPS terminology refers to a single period of observation. Sessions and station designations are usually denoted by alphanumeric characters (0, 1, 2, A, B, C, etc.), determined prior to survey commencement.

(1) When only eight numeric characters are permitted for station/session designations, the following convention may be followed:

12345678

where

1 = type of monument with the following convention being recommended:

1 = known horizontal control monument
2 = known benchmark
3 = known 3D monument
4 = new horizontal control monument
5 = new benchmark
6 = new 3D monument
7 = unplanned occupation
8 = temporary 2D point
9 = temporary 3D point

2, 3, 4 = actual station number given to each station

5, 6, 7 = Julian day of year

8 = session number

(a) Example: Station Identifier: 40011821
Position: 12345678

(b) The numeral 4 in the number 1 position indicates the monument being established is a new monument where only horizontal position is being established.

(c) The 001 in the number 2, 3, and 4 position is the station number that has been given to the monument for this project.

(d) The 182 in the number 5, 6, and 7 position is the Julian day of the year. This is the same day as 1 July.

(e) The numeral 1 in the number 8 position identifies the session number during which observations are being made. If the receiver performed observations during the second session on the same day on the same monument, the session number should be changed to 2 for the period of the second session (then the total station identifier would be 40011822).

(2) When alpha characters are permitted for station/session designation, then a more meaningful designation can be assigned to the designation. The date of each survey session should be recorded during the survey as calendar dates and Julian days and used in the station/session designation. Some GPS software programs will require Julian dates for correct software operation. In addition to determination of station/session designations before the survey begins, the user (usually the crew chief) must:

(a) Determine the occupant of each station.

(b) Determine satellite visibility for each station.

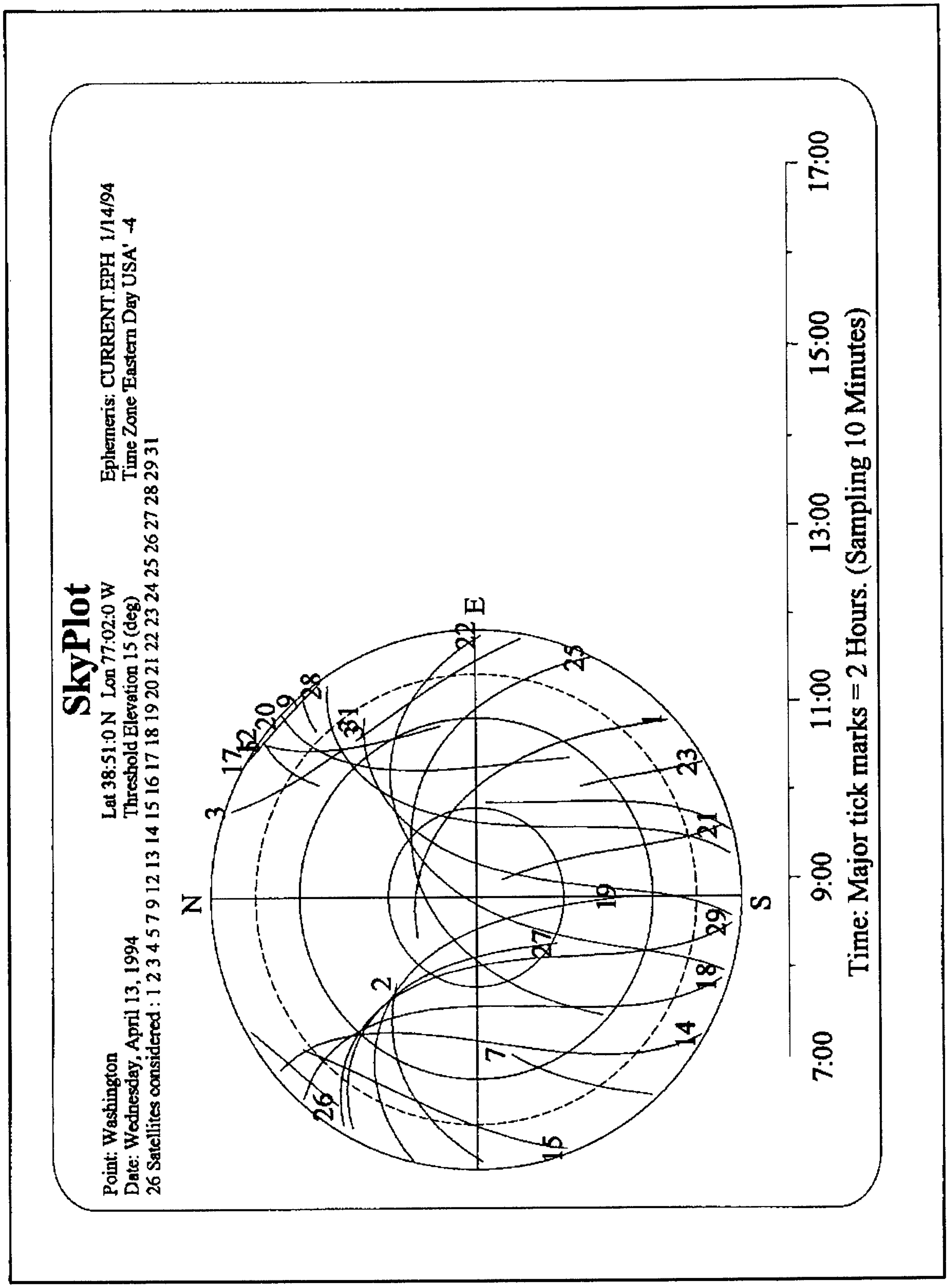


Figure 8-9. Satellite polar plot

SV Constellations

Point: Washington | Lat 38:51:0 N Lon 77:02:0 W | Ephemeris: CURRENT.EPH 1/14/94
Date: Wednesday, April 13, 1994 | Threshold Elevation 15 (deg) | Time Zone 'Eastern Day USA' -4
26 Satellites considered : 1 2 3 4 5 7 9 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 31
Sampling Rate: 10 Minutes

Constellation	T Rise	T Set	dT	PDOP Rise	PDOP Set
4 5 13 16 20 24 26	0:00	0:10	0:10	2.5	2.5
4 13 16 20 24 26	0:10	0:20	0:10	2.5	2.5
3 4 13 16 20 24 26	0:20	0:30	0:10	1.8	1.8
3 4 16 20 24 26	0:30	0:40	0:10	1.9	1.9
3 16 17 24 26	0:40	1:40	1:00	2.9	3.2
3 16 17 23 24 26	1:40	2:00	0:20	2.5	2.5
3 16 17 23 26	2:00	2:40	0:40	3.6	4.4
3 9 16 17 23 26	2:40	3:40	1:00	2.7	3.2
3 9 12 16 17 21 23 26	3:40	3:50	0:10	1.8	1.8
3 9 12 17 21 23 26	3:50	4:10	0:20	2.1	2.2
3 9 12 17 21 23 26 28	4:10	4:20	0:10	2.0	2.0
1 3 9 12 17 21 23 26 28	4:20	4:30	0:10	1.9	1.9
1 3 9 12 17 21 23 26	4:30	4:40	0:10	2.0	2.0
1 9 12 17 21 23 26	4:40	5:00	0:20	2.2	2.2
1 9 12 17 21 23	5:00	5:40	0:40	5.3	4.7
1 5 9 12 17 21 23	5:40	6:00	0:20	3.3	3.2
1 5 9 12 21 23	6:00	6:10	0:10	3.3	3.3
1 5 9 12 20 21 23	6:10	6:20	0:10	2.9	2.9
1 5 9 12 20 21 23 25	6:20	7:00	0:40	2.1	2.1
1 5 12 20 21 23 25	7:00	7:20	0:20	2.4	2.4
1 5 12 15 20 21 23 25	7:20	7:30	0:10	2.0	2.0
1 5 15 20 21 23 25	7:30	8:00	0:30	2.1	1.9
1 5 15 20 21 25	8:00	8:40	0:40	2.8	2.1
1 14 15 20 21 25	8:40	9:00	0:20	2.3	2.3
1 14 20 21 25	9:00	9:10	0:10	2.5	2.5
1 14 20 21 22 25	9:10	9:20	0:10	2.4	2.4
1 14 20 22 25	9:20	10:00	0:40	2.7	2.8
1 14 20 22 25 29	10:00	10:10	0:10	2.3	2.3
1 14 22 25 29	10:10	10:50	0:40	2.8	2.6
3 14 22 25 29	10:50	11:10	0:20	3.1	3.2
3 14 22 25 28 29	11:10	11:20	0:10	2.5	2.5
3 14 18 22 25 28 29	11:20	12:00	0:40	1.9	2.1
3 14 18 22 25 28 29 31	12:00	12:20	0:20	1.9	1.8
3 18 22 25 28 29 31	12:20	12:40	0:20	2.2	2.2
3 18 19 22 28 29 31	12:40	12:50	0:10	2.0	2.0
18 19 22 28 29 31	12:50	13:50	1:00	3.0	4.3
18 19 22 27 28 29 31	13:50	14:50	1:00	2.8	2.2
18 19 27 28 31	14:50	15:00	0:10	3.1	3.1
15 18 19 27 28 31	15:00	15:20	0:20	2.8	2.7
2 15 18 19 27 28 31	15:20	15:40	0:20	1.9	1.8
2 15 19 27 28 31	15:40	15:50	0:10	2.1	2.1
2 15 19 27 31	15:50	16:00	0:10	2.9	2.9
2 7 15 19 27 31	16:00	17:20	1:20	2.4	2.7
2 7 15 19 27	17:20	17:50	0:30	6.8	6.8
2 7 14 15 19 27	17:50	18:00	0:10	5.5	5.5
2 7 13 14 15 27	18:00	18:20	0:20	2.9	2.8
2 4 7 13 14 15 27	18:20	18:40	0:20	2.6	2.4
2 4 7 13 14 15	18:40	18:50	0:10	2.4	2.4
2 4 7 9 13 14 15	18:50	19:00	0:10	2.0	2.0
2 4 7 9 12 13 14 15	19:00	19:20	0:20	2.1	2.3
2 4 7 9 12 13 14	19:20	19:30	0:10	2.8	2.8
2 4 7 9 12 13 14 24	19:30	20:20	0:50	2.2	2.2
2 4 5 7 9 12 13 14 24	20:20	20:50	0:30	1.9	1.7
2 4 5 7 12 13 24	20:50	21:00	0:10	2.5	2.5
4 5 7 12 13 24	21:00	21:30	0:30	3.4	3.7
4 5 7 12 13 18 24	21:30	21:40	0:10	2.9	2.9
4 5 7 12 13 16 18 24	21:40	21:50	0:10	2.7	2.7
4 5 7 12 13 16 18 20 24	21:50	22:00	0.10	1.7	1.7
4 5 7 13 16 18 20 24	22:00	22:30	0:30	1.9	2.0
4 5 13 16 18 20 24	22:30	23:20	0:50	2.4	2.6
4 5 13 16 20 24	23:20	23:50	0:30	3.0	2.7
4 5 13 16 20 24 26	23:50	24:00	0:10	2.5	2.5

Figure 8-10. Satellite azimuth and elevation table

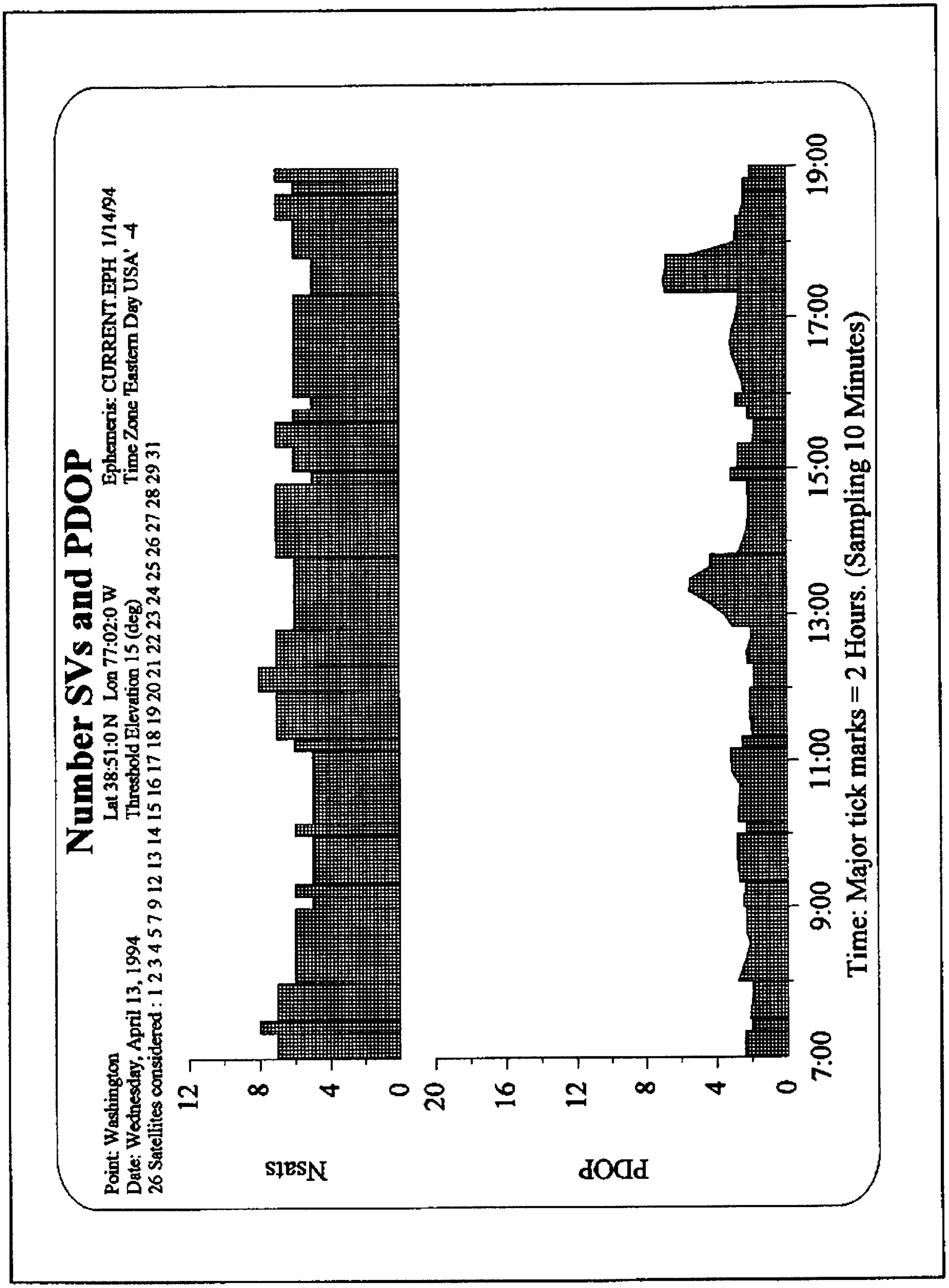


Figure 8-11. PDOP versus time plot

(c) Require site reconnaissance data for stations to be occupied. Remember the same person who performed the initial site reconnaissance may not be the individual performing the survey; therefore, prior determined site reconnaissance data may require clarification before survey commencement.

(d) Develop a project sketch.

(e) Issue explicit instructions on when each session is to begin and end.

(f) Require a station data logging sheet completed for each station. Figures 8-12 and 8-13 are examples of various station logs used in USACE, along with blank forms which may be used as worksheets. Standard bound field survey books may be used in lieu of separate log/work sheets.

U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

PROJECT NAME Coyote Dam LOCALITY Ukiah, CA
OBSERVER Larry Lamb AGENCY/FIRM COE, Sacramento Dist.
RECEIVER Trimble 4000 SL S/N 2820A00223
ANTENNA Trimble Micro SL S/N 2816A00224
DATA RECORDING UNIT Receiver S/N 2820A00223
TRIBRACH Wild GDF 22 S/N N/A LAST CALIBRATED: 4/24/89

	SESSION 1	SESSION 2	SESSION 3
STATION NAME	Pier 2	Pier 2	Pier 2
STATION NUMBER	2002	2002	2002
DAY OF YEAR	115	115	115
DATE MM DD YY	04/25/89	04/25/89	04/25/89
UTC TIME OF OBSERVATION	START 04:56 STOP 05:55	START 06:10 STOP 07:38	START 07:55 STOP 09:20

ANTENNA HEIGHT MEASUREMENTS

	SESSION 1	SESSION 2	SESSION 3
SLOPE @ BEGINNING	0.120 0.120 0.119 4 12/16 IN = 0.121 M MN = 0.120 M	0.116 0.116 0.116 4 9/16 IN = 0.116 M MN = 0.116 M	0.123 0.124 0.124 4 14/16 IN = 0.124 M MN = 0.1238 M
SLOPE @ END	4 11/16 4 12/16 4 11/16 0.120 M = 4 12/16 IN MN = 0.120 M	4 9/16 4 9/16 4 9/16 0.116 M = 4 9/16 IN MN = 0.116 M	4 13/16 4 14/16 4 14/16 0.123 M = 4 13/16 IN MN = 0.1230 M
MN ADJ TO VERT	0.120 M	0.116 M	0.1234 M

	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION
LAT	39-12-30	39-12-22.64	39-12-30	39-12-22.48	39-12-30	39-12-22.81
LONG	123-10-30	123-10-33.42	123-10-30	123-10-33.20	123-10-30	123-10-33.62
HT	244.0	210.6	244.0	199.8	244.0	222.8
PDOP	3.6		4.8		4.0	
SVS TO TRACK	02, 03, 06, 09, 11, 12, 13, 14		02, 03, 06, 09, 11, 12, 13, 14		03, 06, 09, 11, 12, 13, 14, 16	

LOCAL TIME:	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL
START	21:55	21:56	23:38	23:10	01:20	00:55
STOP	22:55	22:55	00:38	00:38	02:20	02:20

PAGE 1

Figure 8-12. Sample GPS data logging sheet (Continued)

U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

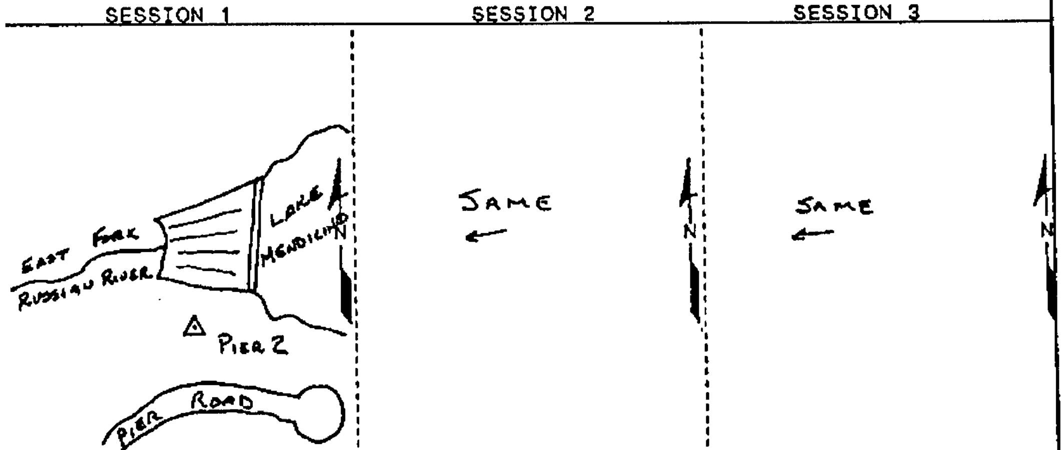
****

	SESSION 1	SESSION 2	SESSION 3
ANT CABLE LENGTH	100 FT	100 FT	35 FT
POWER SUPPLY	12V DC	12V DC	12V DC
WEATHER CONDITIONS	CLEAR, COOL 45°	CLEAR, COOL 40°	CLEAR, BREEZY 40°
MONUMENT TYPE	'C' (SET IN PIER)	← SAME	SAME
EXACT STAMPING	PIER 2 1953	← "	"
AGENCY CAST IN DISK	COE	← "	"

****

SKETCH OF SITE

SESSION 1	SESSION 2	SESSION 3



****

Describe any abnormalities and/or problems encountered during the survey, include session number, time of occurance and duration.

THE ANTENNA WAS MOUNTED DIRECTLY OVER PIER 2 WITH NO TRIPOD USED.

ANTENNA HEIGHT WAS MEASURED VERTICALLY FROM GROUND PLANE TO BRASS DISK.

****

PAGE 2

Figure 8-12. (Concluded)

U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

****
PROJECT NAME ____________________ LOCALITY ____________
OBSERVER ____________________ AGENCY/FIRM ____________
RECEIVER ____________________ S/N ____________
ANTENNA ____________________ S/N ____________
DATA RECORDING UNIT ____________________ S/N ____________
TRIBRACH ____________ S/N ________ LAST CALIBRATED: ________
****

	SESSION 1		SESSION 2		SESSION 3	
STATION NAME	________		________		________	
STATION NUMBER	________		________		________	
DAY OF YEAR	________		________		________	
DATE MM DD YY	________		________		________	
UTC TIME OF OBSERVATION	START	STOP	START	STOP	START	STOP

****

ANTENNA HEIGHT MEASUREMENTS

	SESSION 1	SESSION 2	SESSION 3
SLOPE @ BEGINNING	____ ____ ____ ____ IN =____ M MN = ______ M	____ ____ ____ ____ IN =____ M MN = ______ M	____ ____ ____ ____ IN =____ M MN = ______ M
SLOPE @ END	____ ____ ____ ____ M =____ IN MN = ______ M	____ ____ ____ ____ M =____ IN MN = ______ M	____ ____ ____ ____ M =____ IN MN = ______ M
MN ADJ TO VERT	________ M	________ M	________ M

****

	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION
LAT	______	______	______	______	______	______
LONG	______	______	______	______	______	______
HT	______	______	______	______	______	______
PDOP	______		______		______	
SVS TO TRACK	______		______		______	
LOCAL TIME:	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL
START	______	______	______	______	______	______
STOP	______	______	______	______	______	______

****

PAGE 1

Figure 8-13. Worksheet 8-3, GPS data logging sheet (Continued)

U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

	SESSION 1	SESSION 2	SESSION 3
ANT CABLE LENGTH			
POWER SUPPLY			
WEATHER CONDITIONS			
MONUMENT TYPE			
EXACT STAMPING			
AGENCY CAST IN DISK			

SKETCH OF SITE

SESSION 1	SESSION 2	SESSION 3
N	N	N

Describe any abnormalities and/or problems encountered during the survey, include session number, time of occurance and duration.

PAGE 2

Figure 8-13. (Concluded)

Chapter 9
Conducting GPS Field Surveys

Section I
Introduction

9-1. General

This chapter presents guidance to field personnel performing GPS surveys for all types of USACE projects. The primary emphasis in this chapter is on static and kinematic carrier phase differential GPS measurements which is covered in Section IV. Absolute positioning is covered in Section II. Section III covers differential code phase GPS positioning techniques.

9-2. General GPS Field Survey Procedures

The following are some general GPS field survey procedures that should be performed at each station, observation, and/or session on a GPS survey.

a. Receiver setup. GPS receivers shall be set up in accordance with manufacturer's specifications prior to beginning any observations. To eliminate any possibility of missing the beginning of the observation session, all equipment should be set up with power supplied to the receivers at least 10 min prior to the beginning of the observation session. Most receivers will lock-on to satellites within 1-2 min of powering up.

b. Antenna setup. All tribrachs used on a project should be calibrated and adjusted prior to beginning each project. Dual use of both optical plummets and standard plumb bobs is strongly recommended since centering errors represent a major error source in all survey work, not just GPS surveying.

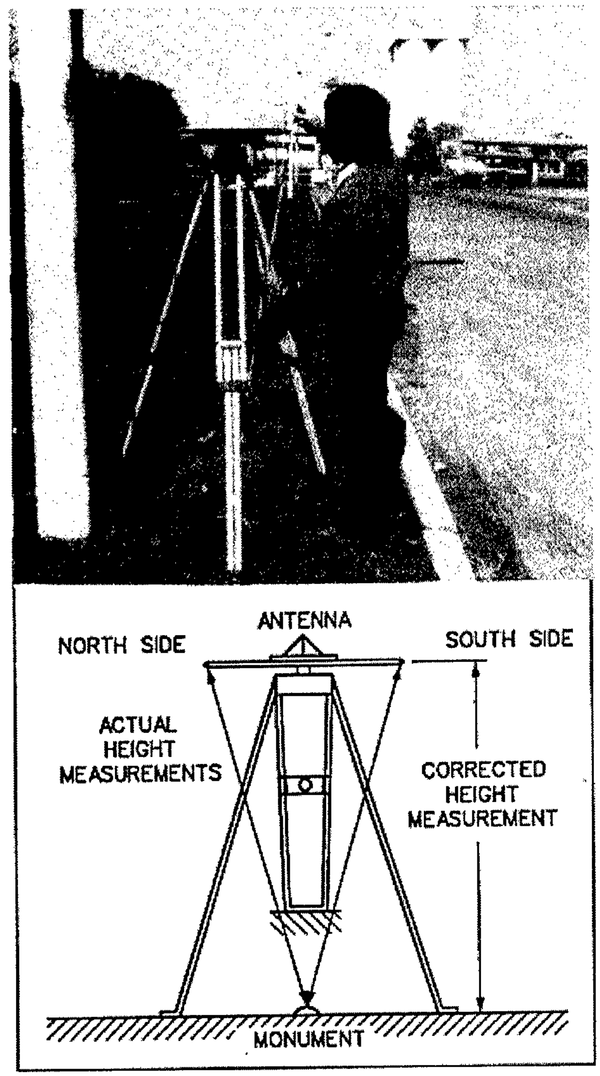


Figure 9-1. Height of instrument measurement setup

c. Height of instrument measurements. Height of instrument (HI) refers to the correct measurement of the distance of the GPS antenna above the reference monument over which it has been placed. HI measurements will be made both before and after each observation session. The HI will be made from the monument to a standard reference point on the antenna. (See Figure 9-1.) These standard reference points for each antenna will be established prior to the beginning of the observations so all observers will be measuring to the same point. All HI measurements will be made both in meters and feet for redundancy and blunder detection. HI measurements shall be determined to the nearest millimeter in metric units and to the nearest 0.01 ft (or 1/16 in.). It should be noted whether the HI is vertical or diagonal.

d. Field GPS observation recording procedures. Field recording books, log sheets, or log forms will be completed for each station and/or session. Any acceptable recording media may be used. For archiving purposes, standard bound field survey books are preferred; however, USACE Commands may require specific recording sheets/forms to be used in lieu of a survey book. The amount of record-keeping detail will be project-dependent; low-order

topographic mapping points need not have as much descriptive information as would permanently marked primary control points. The following typical data may be included on these field log records:

(1) Project, construction contract, observer(s) name(s), and/or contractor firm and contract number.

(2) Station designation.

(3) Station file number.

(4) Date, weather conditions, etc.

(5) Time start/stop session (local and UTC).

(6) Receiver, antenna, data recording unit, and tribrach make, model, and serial numbers.

(7) Antenna height: vertical or diagonal measures in inches (or feet) and meters (or centimeters).

(8) Space vehicle designations (satellite number).

(9) Sketch of station location.

(10) Approximate geodetic location and elevation.

(11) Problems encountered.

USACE Commands may require that additional data be recorded. These will be contained in individual project instructions or contract delivery order scopes. Samples of typical GPS recording forms are shown later in this chapter.

e. Field processing and verification. It is strongly recommended that GPS data processing and verification be performed in the field where applicable. This is to identify any problems that may exist which can be corrected before returning from the field. Processing and verification is covered in Chapters 10 and 11.

Section II
Absolute GPS Positioning Techniques

9-3. General

The accuracy obtained by GPS point positioning is dependent on the user's authorization. The SPS user can provide an accuracy of 80-100 m. SPS data are most often expressed in real time; however, the data can be post-processed if station occupation was over a period of time. The post-processing produces a best-fit point position. Although this will provide a better internal approximation, the effects of S/A when activated still degrade positional accuracy up to 80-100 m. The PPS user requires a decryption device within the receiver to decode the effects of S/A. The PPS provides an accuracy between 10 and 16 m when a single-frequency receiver is used for observation. Dual-frequency receivers using the precise ephemeris may produce an absolute positional accuracy on the order of 1 m or better. These positions are based on the absolute WGS 84 ellipsoid. The PPS that uses the precise ephemeris requires the data to be post-processed. At present, a commercial or military receiver capable of meter-level GPS point positioning without post-processing is not available.

9-4. Absolute (Point Positioning) Techniques

There are two techniques used for point positioning in the absolute mode. They are long-term averaging of positions and differencing between signals.

a. In long-term averaging, a receiver is set up to store positions over a period of observation time. The length of observation time varies based upon the accuracy required. The longer the period of data collection, the better average position. These observation times can range between 1 and 24 hr. This technique can also be used in real-time (i.e., the receiver averages the positions as they are calculated). For example, the precise lightweight GPS receiver (PLGR) GPS receiver uses this technique in calculating a position at a point.

b. The process of differencing between signals can only be performed in a post-processed mode. Currently, the Defense Mapping Agency has produced software that can perform this operation.

Section III
Differential Code Phase GPS Positioning Techniques

9-5. General

Differential (or relative) GPS surveying is the determination of one location with respect to another location. When using this technique with the C/A- or P-code it is called relative code phase positioning or surveying. Relative code phase positioning has limited application to detailed engineering surveying and topographic site plan mapping applications. Exceptions include general

reconnaissance surveys, hydrographic survey vessel or dredge positioning (see EM 1110-2-1003 for further information on these surveys), and some operational military or geodetic survey support functions. Additional applications for relative code phase positioning have been on the increase as positional accuracies have become better.

9-6. Relative Code Phase Positioning

The code phase tracking differential system is currently a functional GPS survey system for positioning hydrographic survey vessels and dredges. It also has application for topographic, small-scale mapping surveys and input to a GIS database. The basic concept is shown in Figure 9-2. Although greater positional accuracies can be obtained with use of the P-code, DoD's implementation of A/S will limit its use. A real-time dynamic DGPS positioning system includes a reference station, communication link, and user (remote) equipment. If results are not required in real-time, the communication link can be eliminated and the positional information is post-processed.

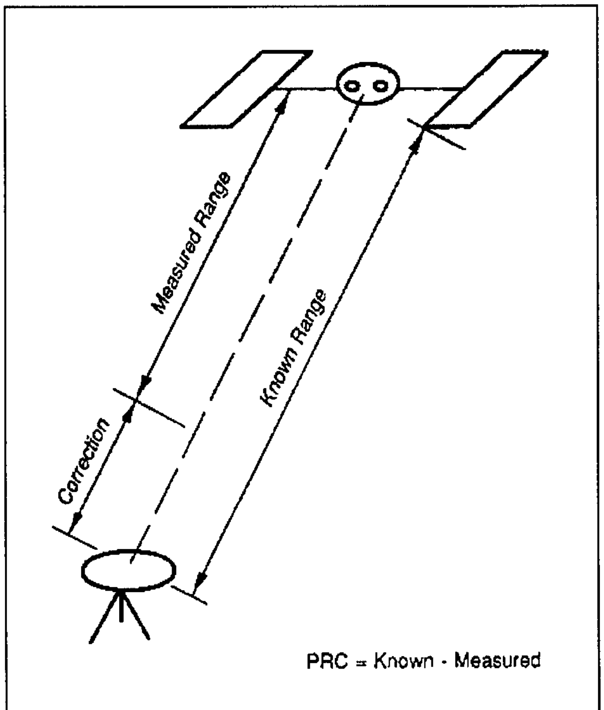


Figure 9-2. Code phase DGPS concept

a. Accuracy of relative code surveys. Relative code phase surveys can obtain accuracies of 0.5 to 10 m. These accuracies will meet Class 1 hydrographic survey standards as stated in EM 1110-2-1003. This type of survey could also be used for small-scale mapping or used as input to a GIS database.

b. Reference station. The reference station is placed on a known survey monument in an area having an unobstructed view of the sky of at least four satellites, 10 deg above the horizon. It consists of a GPS receiver, GPS antenna, processor, and a communication link (if real-time results are desired). The reference station measures the timing and ranging information broadcast by the satellites and computes and formats range corrections for broadcast to the user equipment. Using the technology of differential pseudo-ranging, the position of a survey vessel is found relative to the reference station. The pseudo-ranges are collected by the GPS receiver and transferred to the processor where PRCs are computed and formatted for data transmission. Many manufacturers have incorporated the processor within the GPS receiver, eliminating the need for an external processing device. The recommended data format is that proposed by the RTCM Special Committee (SC) 104 v. 2.0. The processor should be capable of computing and formatting PRCs every 1-3 sec. A longer time span could affect the user's positional solution due to effects of S/A.

c. Communication link. The communication link is used as a transfer media for differential corrections. The main requirement of the communication link is that transmission be at a minimum rate of 300 bits per second. The type of communication system is dependent on the user's requirements.

(1) Frequency authorization. All communication links necessitate a reserved frequency for operation to avoid interference with other activities in the area. No transmission can occur over a frequency until the frequency has been officially authorized for use in transmitting digital data. This applies to all government agencies. Allocating a frequency is handled by the FOA's Frequency Manager responsible for the area of application, the vendor supplying the equipment, and the user.

(2) Ultra High Frequency (UHF) and Very High Frequency (VHF). Communication links operating at UHF and VHF are viable systems for the broadcast of DGPS corrections. UHF and VHF can extend out some 20 to 50 km, depending on local conditions. The disadvantages of UHF and VHF links are their limited range to line of sight and the effects of signal shadowing (i.e. islands, structures, and buildings), multipath and licensing issues.

(3) Satellite communications. There are several companies that sell satellite communication systems which can be used for the transmission of PRCs. These systems can be efficient for wide areas, but are usually higher in price.

(4) License-free radio-modems. Several companies have developed low wattage (1 watt or less) radio-modems to transmit digital data. These radio-modems require no license and can be used to transmit DGPS corrections in a localized area (within 5-8 km or less depending on line of sight). The disadvantages are the short range and line-of-sight limitations.

d. User (remote station) equipment. The remote receiver should be a multichannel single frequency C/A-code GPS receiver. The receiver must be able to store the raw data to be post-processed. During post-processing, these PRCs are generated with the GPS data from the reference station and then applied to the remote station data to obtain a corrected position. If the results are desired in real time, the receiver must be able to accept the PRCs from the reference station (via data link) in the RTCM SC 104 v. 2.0 format and apply those corrections to the measured pseudo-range. The corrected position can then be input into a data collector, hydro package, or GIS database.

e. USCG DGPS Navigation Service. The USCG DGPS Navigation Service was developed to provide a nationwide (coastal regions, Great Lakes regions, and some inland waterways), all-weather, real-time, radio navigation service in support of commercial and recreational maritime interests. A 50+ station network will be operational by FY96. Its accuracy was originally designed to fulfill an 8- to 20-m maritime navigation accuracy. However, a reconfigured version of the USCG system will now yield 1.5-m 2DRMS at distances upward of 150 km from the reference beacon. The system operates on the USCG marine radio beacon frequencies (285-325 kHz). Each radio beacon has an effective range of 150 to 250 km at a 99.9 percent signal availability level. It is fully expected that the USCG system, once completed will be the primary marine navigation device used by commercial and recreational vessels requiring meter-level accuracy.

(a) Corps-wide implementation and use of the USCG system will eliminate need for maintaining existing USACE-operated microwave positioning systems. It will also significantly reduce or eliminate USACE requirements to develop independent UHF/VHF DGPS networks for meter-level vessel navigation and positioning.

(b) The USCG system has potential for supporting other nonmarine activities such as master planning, engineering, mapping, operations, and GIS development activities where meter-level accuracy is sufficient.

Section IV
Differential Carrier Phase GPS Horizontal Positioning Techniques

9-7. General

Differential (or relative) GPS carrier phase surveying is used to obtain the highest precision from GPS and has direct application to most USACE military construction and civil works topographic and engineering survey activities.

a. Differential survey techniques. There are basically six different GPS differential surveying techniques (paragraph 6-4) in use today:

(1) Static.

(2) Pseudo-kinematic.

(3) Stop and go kinematic.

(4) Kinematic.

(5) Rapid static.

(6) On-the-fly (OTF)/Real-time kinematic (RTK).

Procedures for performing each of these methods are described below. These procedures are guidelines for conducting a field survey. Manufacturers' procedures should be followed, when appropriate, for conducting a GPS field survey. Project horizontal control densification can be performed using any one of these methods. Procedurally, all six methods are similar in that each measures a 3D baseline vector between a receiver at one point (usually of known local project coordinates) and a second receiver at another point, resulting in a vector difference between the two points occupied. The major distinction between static and kinematic baseline measurements involves the method by which the carrier wave integer cycle ambiguities are resolved; otherwise they are functionally the same process.

b. Ambiguity resolution. Cycle ambiguity is the unknown number of whole carrier wavelengths between the satellite and receiver. It is also referred to as "Integer

Ambiguity." Figure 9-3 shows an example of an integer ambiguity measurement. Successful ambiguity resolution is required for successful baseline formulations. Generally, in static surveying, instrumental error and ambiguity resolution can be achieved through long-term averaging and simple geometrical principles, resulting in solutions to a linear equation that produces a resultant position. But ambiguity resolution can also be achieved through a combination of the pseudo-range and carrier beat measurements, made possible by a knowledge of the PRN modulation code.

c. Post-observation data reduction. Currently, all carrier phase relative surveying techniques, except OTF and RTK, require post-processing of the observed data to determine the relative baseline vector differences. OTF and RTK can be performed in real-time or in the post-processed mode. Post-processing of observed satellite data involves the differencing of signal phase measurements recorded by the receiver. The differencing process reduces biases in the receiver and satellite oscillators and is performed in a computer. When contemplating the purchase of a receiver, the user should keep in mind the computer requirements necessary to post-process the GPS data. Most manufacturers require, as a minimum, a 386-based IBM-compatible personal computer (PC) with a math co-processor. It is also strongly recommended that all baseline reductions be performed in the field, if possible, in order to allow an onsite assessment of the survey adequacy.

9-8. Static GPS Survey Techniques

Static GPS surveying is perhaps the most common method of densifying project network control. Two GPS receivers are used to measure a GPS baseline distance. The line between a pair of GPS receivers from which simultaneous GPS data have been collected and processed is a vector referred to as a baseline. The station coordinate differences are calculated in terms of a 3D, earth-centered coordinate system that utilizes X-, Y-, and Z-values based on the WGS 84 geocentric ellipsoid model. These coordinate differences are then subsequently shifted to fit the local project coordinate system.

a. General. GPS receiver pairs are set up over stations of either known or unknown location. Typically one of the receivers is positioned over a point whose coordinates are known (or have been carried forward as on a traverse), and the second is positioned over another point

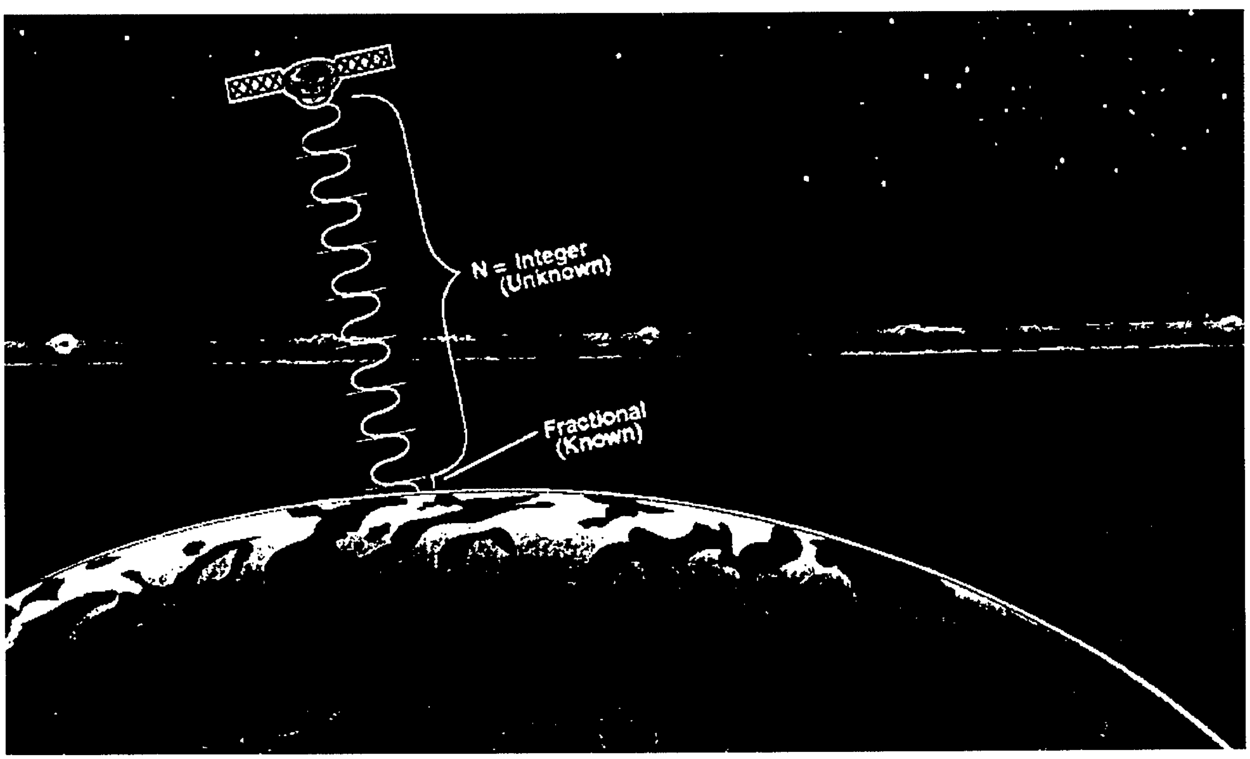


Figure 9-3. Integer Ambiguity

whose coordinates are unknown, but are desired. Both GPS receivers must receive signals from the same four (or more) satellites for a period of time that can range from a few minutes to several hours, depending on the conditions of observation and precision required.

b. Static baseline occupation time. Station occupation time is dependent on baseline length, number of satellites observed, and the GPS equipment used. In general, 30 min to 2 hr is a good approximation for baseline occupation time for shorter baselines of 1-30 km. A rough guideline developed by Trimble, Inc., for estimating occupation time is shown in Figure 9-4. Note that this guideline exceeds the recommended minimum observing times prescribed in Table 8-1.

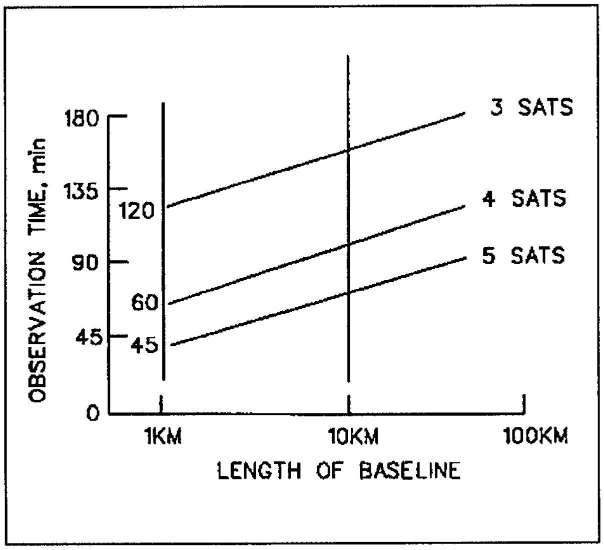


Figure 9-4. Station occupation time versus baseline distance

(1) Since there is no definitive guidance for determining the required baseline occupation time, the results from the baseline reduction (and subsequent adjustments) will govern the adequacy of the observation irrespective of the actual observation time. The most prudent policy is to exceed the minimum estimated times, especially for lines where reoccupation would be difficult or field data assessment capabilities are limited.

(2) For baselines greater than 50 km in length, the ionosphere may have an adverse effect on the solution. Adverse ionosphere effects for baselines of this length can be reduced by using a dual-frequency GPS receiver, as opposed to a single frequency as is normally used.

c. Satellite visibility requirements. The stations that are selected for survey must have an unobstructed view of the sky for at least 15 deg or greater above the horizon during the "observation window." An observation window is the period of time when observable satellites are in the sky and the survey can be successfully conducted.

d. Common satellite observations. It is critical for a static survey baseline reduction/solution that the receivers simultaneously observe the same satellites during the same time interval. For instance, if receiver No. 1 observes a satellite set during the time interval 1,000 to 1,200 and another receiver, receiver No. 2, observes that same satellite set during the time interval 1,100 to 1,300, only the period of common observation, 1,100 to 1,200, can be processed to formulate a correct vector difference between these receivers.

e. Data post-processing. After the observation session has been completed, the received GPS signals from both receivers are then processed (i.e., "post-processed") in a computer to calculate the 3D baseline vector components between the two observed points. From these vector distances, local or geodetic coordinates may be computed and/or adjusted.

f. Survey configuration. Static baselines may be extended from existing control using any of the control densification methods described in Chapter 8. These include networking, traverse, spur techniques, or combinations thereof. Specific requirements are normally contained in project instructions (or scope of work) provided by the District office.

g. Receiver operation and data reduction. Specific receiver operation and baseline data post-processing requirements are very manufacturer-dependent. The user is strongly advised to consult and study manufacturer's operations manuals thoroughly along with the baseline data reduction examples shown in this manual.

h. Accuracy of static surveys. Accuracy of GPS static surveys will usually exceed 1 ppm. Currently of all GPS processing methods, static is the most accurate and can be used for any order survey.

9-9. Stop-and-Go Kinematic GPS Survey Techniques

Stop-and-go surveying is similar to static surveying in that each method requires at least two receivers simultaneously

recording observations. A major difference between static and stop-and-go surveying is the amount of time required for a receiver to stay fixed over a point of unknown position. In stop-and-go surveying, the first receiver--the home or reference receiver--remains fixed on a known control point. The second receiver--the "rover" receiver--collects observations statically on a point of unknown position for a period of time (usually a few minutes), and then moves to subsequent unknown points to collect signals for a short period of time. During the survey, at least four common satellites (preferably five) need to be continuously tracked by both receivers. Once all required points have been occupied by the rover receiver, the observations are then post-processed by a computer to calculate baseline vector/coordinate differences between the known control point and points occupied by the rover receiver during the survey session. The main advantage of this form of GPS surveying over static surveying is the reduced occupation time required over the unknown points. Because stop-and-go surveying requires less occupation time over unknown points, time and cost for the conduct of a survey are significantly reduced. Achievable accuracies typically equal or exceed Third-Order, which is adequate for most USACE projects.

a. Survey procedure. A typical stop-and-go survey scheme is illustrated in Figure 9-5. Stop-and-go GPS surveying is performed similarly to a conventional EDM traverse or electronic total station radial survey. The system is initially calibrated by performing either an antenna swap (see *d* below) with one known point and one unknown point or by performing a static measurement over a known baseline. This calibration process is performed to resolve initial cycle ambiguities. This known baseline may be part of the existing network or can be established using static GPS survey procedures described above. The remote roving receiver then traverses between unknown points as if performing a radial topographic survey. Typically, the points are double-connected, or double-run, as in a level line. Optionally, two fixed receivers may be used to provide redundancy on the remote points. With only 1-1/2 min at a point, X-Y-Z coordinate production is high and limited only by satellite observing windows, travel time between points, and overhead obstructions.

b. Satellite lock. During a stop-and-go kinematic survey, the rover station must maintain lock on at least four satellites during the period of survey (the reference station must be observing at least the same four satellites). Loss of lock occurs when the receiver is unable to continuously record satellite signals or the transmitted satellite

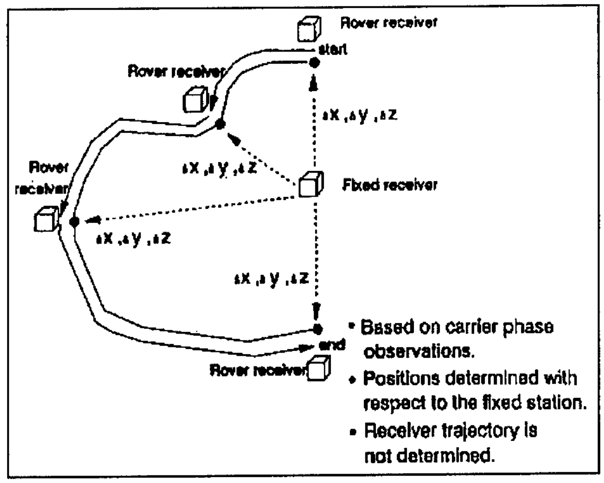


Figure 9-5. Typical stop-and-go survey scheme

signal is disrupted and the receiver is not able to record it. If satellite lock is lost, the roving receiver must reobserve the last control station surveyed before loss of lock. The receiver operator must monitor the GPS receiver when performing the stop-and-go survey to ensure loss of lock does not occur. Some manufacturers have now incorporated an alarm into their receiver that warns the user when loss of lock occurs, thus making the operator's job of monitoring the receiver easier.

c. Site constraints. Survey site selection and route between rover stations to be observed are critical. All sites must have a clear view of satellites having a vertical angle of 15 deg or greater. The routes between rover occupation stations must be clear of obstructions so that the satellite signal is not interrupted. Each unknown station to be occupied should be occupied for a minimum of at least 1-1/2 min. Stations should be occupied two or three times to provide redundancy between observations.

d. Antenna swap calibration procedure. Although the antenna swap procedure can be used to initialize a survey prior to a stop-and-go survey, an antenna swap can also be used to determine a precise baseline and azimuth between two points. The procedure requires that both stations occupied and the path between both stations maintain an unobstructed view of the horizon. A minimum of four satellites and maintainable lock are required to perform an antenna swap; however, more than four satellites are preferred. To perform an antenna swap, one receiver/antenna is placed over a point of known control and the second, a distance of 10 to 100 m away from the other receiver. Referring to Figure 9-6, the receivers at each

station collect data for approximately 2 to 4 min. The receivers/antennae sets then swap locations; the receiver/antenna at the known station is moved to the unknown site while the other receiver/antenna at the unknown site is moved to the known site. Satellite data are again collected for 2 to 4 min. The receivers are then swapped back to their original locations. This completes one antenna swap calibration. If satellite lock is lost during the procedure, the procedure must be repeated.

e. Accuracy of stop-and-go surveys. Accuracy of stop-and-go baseline measurements will usually well exceed 1 part in 5,000; thus, Third-Order classification project/mapping horizontal control can be effectively, efficiently, and accurately established using this technique. For many USACE projects, this order of horizontal accuracy will be more than adequate; however, field procedures should be designed to provide adequate redundancy for what are basically "open-ended" or "spur" points. Good satellite geometry and minimum multipath are also essential in performing acceptable stop-and-go surveys.

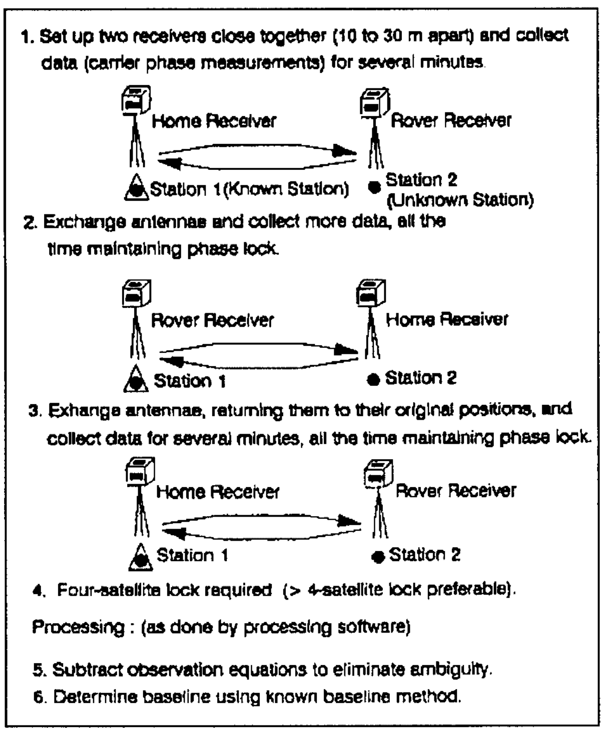


Figure 9-6. Stop-and-go ambiguity resolution (antenna swap method)

9-10. Kinematic GPS Survey Techniques

Kinematic surveying using differential carrier phase tracking is similar to the two previous types of differential carrier phase GPS surveying because it also requires two receivers recording observations simultaneously. Kinematic surveying is often referred to as dynamic surveying. As in stop-and-go surveying, the reference receiver remains fixed on a known control point while the roving receiver collects data on a constantly moving platform (vehicle, vessel, aircraft, manpack, etc.), as illustrated in Figure 9-7. Unlike stop-and-go surveying, kinematic surveying techniques do not require the rover receiver to remain motionless over the unknown point. The observation data are later post-processed with a computer to calculate relative vector/coordinate differences to the roving receiver.

a. Survey procedure. A kinematic survey requires two single frequency (L1) receivers. One receiver is set over a known point (reference station) and the other is used as a rover (i.e., moved from point to point or along a path). Before the rover receiver can rove, a period of static initialization or antenna swap (see paragraph 9-9*d*) must be performed. This period of static initialization is dependent on the number of satellites visible. Once this is done, the rover receiver can move from point to point as long as satellite lock is maintained on at least four common (with the reference station) satellites. If loss of satellite lock occurs, a new period of static initialization must take place. It is important to follow manufacturers' specifications when performing a kinematic survey.

b. Kinematic data processing techniques. In general, kinematic data processing techniques are similar to those used in static surveying (Chapter 10). When processing kinematic GPS data, the user must ensure that satellite lock was maintained on four or more satellites and that cycle slips are adequately resolved in the data recorded.

c. Accuracy of kinematic surveys. Differential (carrier phase) kinematic survey errors are correlated between observations received at the reference and rover receivers, as in differential static surveys. Experimental test results indicate kinematic surveys can produce results in centimeters. Test results from an experimental full kinematic GPS survey conducted by U.S. Army Engineer Topographic Laboratory (now TEC) personnel at White Sands Missile Range, Holloman Air Force Base, New Mexico, verified (under ideal test conditions) that kinematic GPS

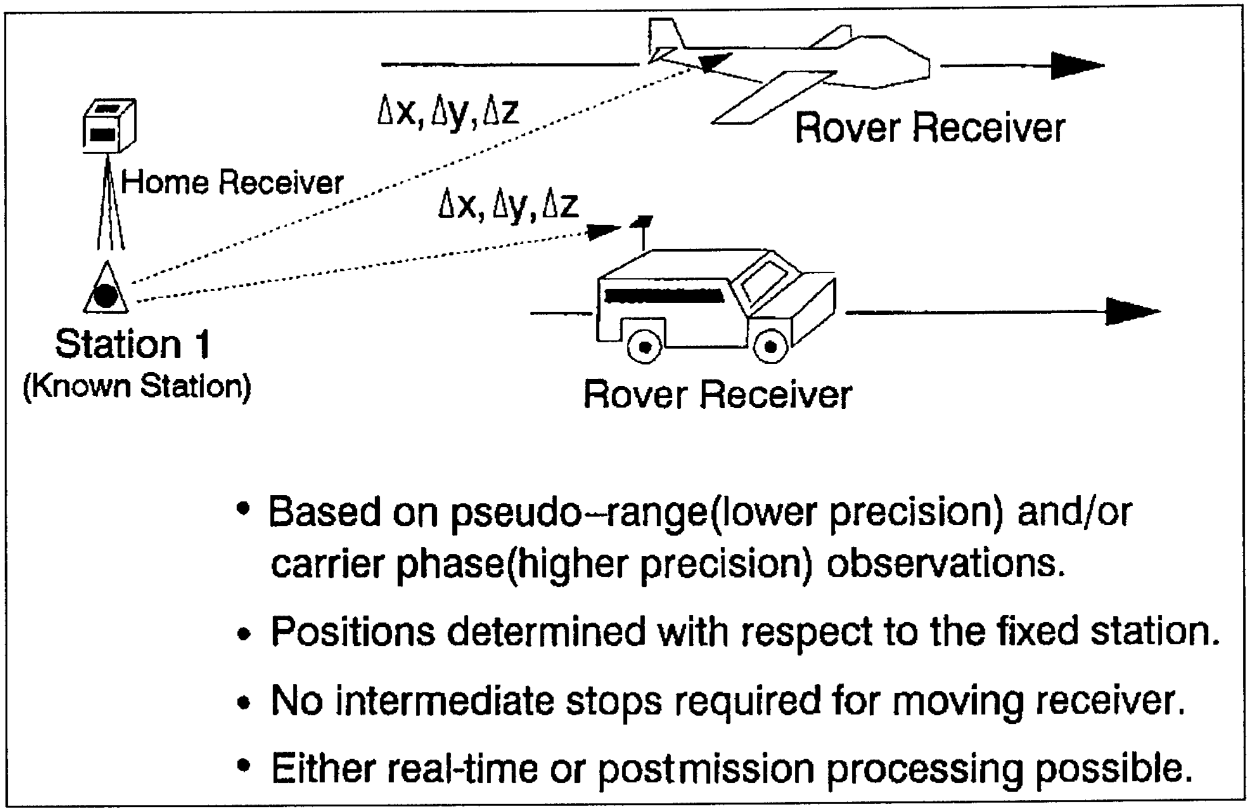


Figure 9-7. Kinematic survey techniques

surveying could achieve centimeter-level accuracy over distances up to 30 km.

9-11. Pseudo-Kinematic GPS Survey Techniques

Pseudo-kinematic GPS surveying is similar to stop-and-go techniques except that loss of satellite lock is tolerated when the receiver is transported between occupation sites (in fact, the roving receiver can be turned off during movement between occupation sites, although this is not recommended). This feature provides the surveyor with a more favorable positioning technique since obstructions such as bridge overpasses, tall buildings, and overhanging vegetation are common. Loss of lock that may result due to these obstructions is more tolerable when pseudo-kinematic techniques are employed.

a. General. The pseudo-kinematic techniques require that one receiver be placed over a known control station. A rover receiver occupies each unknown station for 5 min. Approximately 1 hr after the initial station occupation, the same rover receiver must reoccupy each unknown station.

b. Common satellite requirements. The pseudo-kinematic technique requires that at least four of the same satellites are observed between initial station occupations and the requisite reoccupation. For example, the rover receiver occupies Station A for the first 5 min and tracks satellites 6, 9, 11, 12, 13; then 1 hr later, during the second occupation of Station A, the rover receiver tracks satellites 2, 6, 8, 9, 19. In this example, only satellites 6 and 9 are common to the two sets, so the data cannot be processed because four common satellites were not tracked for the initial station occupation and the requisite reoccupation.

c. Planning. Prior mission planning is essential in conducting a successful pseudo-kinematic survey. Especially critical is the determination of whether or not common satellite coverage will be present for the desired period of the survey. Also, during the period of observation, one receiver, the base receiver, must continuously occupy a known control station.

d. Pseudo-kinematic data processing. Pseudo-kinematic survey satellite data records and resultant baseline

processing methods are similar to those performed for static GPS surveys. Since the pseudo-kinematic technique requires each station to be occupied for 5 min and then reoccupied for 5 min approximately an hour later, this technique is not suitable when control stations are widely spaced and transportation between stations within the allotted time is impractical.

e. Accuracy of pseudo-kinematic surveys. Pseudo-kinematic survey accuracies are similar to kinematic survey accuracies of a few centimeters.

9-12. Rapid Static Surveying Procedures

Rapid static surveying is a combination of the stop-and-go kinematic, pseudo-kinematic, and static surveying methods. The rover or remote receiver spends only a short time on each station, loss of lock is allowed between stations, and accuracies are similar to static. However, rapid static surveying does not require re-observation of remote stations like pseudo-kinematic. The rapid static technique does require the use of dual-frequency (L1/L2) GPS receivers with either cross correlation or squaring or any other technique used to compensate for A-S.

a. Survey procedure. Rapid static surveying requires that one receiver be placed over a known control point. A rover or remote receiver occupies each unknown station for 5-20 min, depending on the number of satellites and their geometry. Because most receiver operations are manufacturer-specific, following the manufacturers' guidelines and procedures for this type of survey is important.

b. Rapid static data processing. Data collected in the rapid static mode should be processed in accordance with the manufacturer's specifications. See Chapter 10 for more information on post-processing GPS data.

c. Accuracy of rapid static surveys. Accuracies of rapid static surveys are similar to static surveys of a centimeter or less. This method can be used for medium-to-high accuracy surveys up to 1/1,000,000.

9-13. OTF/RTK Surveying Techniques

OTF/RTK surveying is similar to kinematic differential GPS surveying because it requires two receivers recording observations simultaneously and allows the rover receiver to be moving. Unlike kinematic surveying, OTF/RTK surveying techniques use dual-frequency L1/L2 GPS observations and can handle loss of satellite lock. Since OTF/RTK uses the L2 frequency, the GPS receiver must be capable of tracking the L2 frequency during A-S. There are several techniques used to obtain L2 during A-S. These include the squaring and cross-correlation methods.

a. Ambiguity resolution. As explained before in paragraph 9-7*b*, successful ambiguity resolution is required for successful baseline formulations. The OTF/RTK technology allows the remote to initialize and resolve these integers without a period of static initialization. With OTF/RTK, if loss of satellite lock occurs, initialization can occur while in motion. The integers can be resolved at the rover within 10-30 sec, depending on the distance from the reference station. OTF/RTK uses the L2 frequency transmitted by the GPS satellites in the ambiguity resolution. After the integers are resolved, only the L1 C/A is used to compute the positions.

b. Survey procedure. OTF/RTK surveying requires dual frequency L1/L2 GPS receivers. One of the GPS receivers is set over a known point, and the other is placed on a moving or mobile platform. If the survey is performed in real time, a data link and a processor (external or internal) are needed. The data link is used to transfer the raw data from the reference station to the remote.

(1) Internal processor. If the OTF/RTK system is done with an internal processor (i.e., built into the receiver), follow manufacturer's guidelines.

(2) External processor. If OTF/RTK is performed with external processors (i.e., notebook computer), then computer at the reference (386-based PC) collects the raw GPS data and formats it to be sent via a data link to the remote. The notebook computer at the rover (486/33 based PC) processes the raw data from the reference and remote receivers to resolve the integers and obtain a position.

c. Accuracy of OTF/RTK surveys. OTF/RTK surveys are accurate to within 10 cm when the distance from the reference to the rover does not exceed 20 k. Results of testing by TEC produced results of less then 10 cm.

Chapter 10
Post-processing Differential GPS Observational Data

10-1. General

GPS baseline solutions are usually generated through an iterative process. From approximate values of the positions occupied and observation data, theoretical values for the observation period are developed. Observed values are compared to computed values, and an improved set of positions occupied is obtained using least squares minimization procedures and equations modeling potential error sources.

a. Processing time is dependent on the accuracy required, software development, computer hardware used, data quality, and amount of data. In general, high accuracy solutions, crude computer software and hardware, low-quality data, and high volumes of data will cause longer processing times.

b. The ability to determine positions using GPS is dependent on the effectiveness of the user to determine the range or distance of the satellite from the receiver located on the earth. There are two general techniques currently operational to determine this range: pseudo-ranging and carrier beat phase measurement. These techniques are discussed in further detail below.

c. The user must take special care when attempting a baseline formulation with observations from different GPS receiver manufacturers. It is important to ensure that observables being used for the formulation of the baseline are of a common format (i.e., RINEX). The common data exchange formats required for a baseline formulation exist only between receivers produced by the same manufacturer, but there are some exceptions.

d. This chapter will discuss general post-processing issues. Due to the increasing number and variety of software packages available, consult the manufacturer guidelines when appropriate.

10-2. Pseudo-Ranging

The pseudo-range observable is calculated from observations recorded during a GPS survey. The pseudo-range observable is the difference between the time of signal transmission from the satellite, measured in the satellite time scale, and the time of signal arrival at the receiver antenna, measured in the receiver time scale. When the differences between the satellite and the receiver clocks are reconciled and applied to the pseudo-range observables, the resulting values are corrected pseudo-range values. The value found by multiplying this time difference by the speed of light is an approximation of the true range between the satellite and the receiver, or a true pseudo-range. A more exact approximation of true range between the satellite and receiver can be determined if ionosphere and troposphere delays, ephemeris errors, measurement noise, and unmodeled influences are taken into account while pseudo-ranging calculations are performed. The pseudo-range can be obtained from either the C/A-code or the more precise P-code (if access is available).

10-3. Carrier Beat Phase Observables

The carrier beat phase observable is the phase of the signal remaining after the internal oscillated frequency generated in the receiver is differenced from the incoming carrier signal of the satellite. The carrier beat phase observable can be calculated from the incoming signal or from observations recorded during a GPS survey. By differencing the signal over a period or epoch of time, one can count the number of wavelengths that cycle through the receiver during any given specific duration of time. The unknown cycle count passing through the receiver over a specific duration of time is known as the cycle ambiguity. There is one cycle ambiguity value per satellite/receiver pair as long as the receiver maintains continuous phase lock during the observation period. The value found by measuring the number of cycles going through a receiver during a specific time, when given the definition of the transmitted signal in terms of cycles per second, can be used to develop a time measurement for transmission of the signal. Once again, the time of transmission of the signal can be multiplied by the speed of light to yield an approximation of the range between the satellite and receiver. The biases for carrier beat phase measurement are the same as for pseudo-ranges although a higher accuracy can be obtained using the carrier. A more exact range between the satellite and receiver can be formulated when the biases are taken into account during derivation of the approximate range between the satellite and receiver.

10-4. Baseline Solution by Linear Combination

The accuracy achievable by pseudo-ranging and carrier beat phase measurement in both absolute and relative positioning surveys can be improved through processing

that incorporates differencing of the mathematical models of the observables. Processing by differencing takes advantage of correlation of error (e.g., GPS signal, satellite ephemeris, receiver clock, and atmospheric propagation errors) between receivers, satellites, and epochs, or combinations thereof, in order to improve GPS processing. Through differencing, the effects of the errors that are common to the observations being processed are eliminated or at least greatly reduced. Basically, there are three broad processing techniques that incorporate differencing: single differencing, double differencing, and triple differencing. Differenced solutions generally proceed in the following order: differencing between receivers takes place first, between satellites second, and between epochs third.

a. Single differencing. There are three general single differencing processing techniques: between receivers, between satellites, and between epochs (see Figure 10-1).

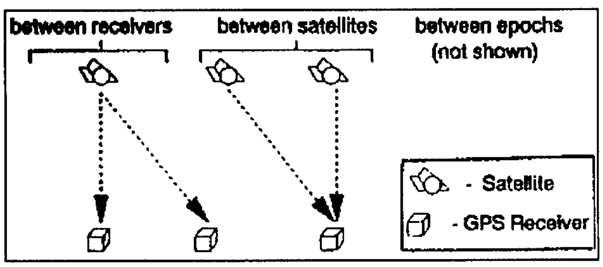


Figure 10-1. Single differencing

(1) Between receivers. Single differencing the mathematical models for a pseudo-range (P- or C/A-code) or carrier phase observable measurements between receivers will eliminate or greatly reduce satellite clock errors and a large amount of satellite orbit and atmospheric delays.

(2) Between satellites. Single differencing the mathematical models for pseudo-range or carrier phase observable measurements between satellites eliminates receiver clock errors. Single differencing between satellites can be done at each individual receiver during observations as a precursor to double differencing and in order to eliminate receiver clock errors.

(3) Between epochs. Single differencing the mathematical models between epochs takes advantage of the Doppler shift or apparent change in the frequency of the satellite signal by the relative motion of the transmitter and receiver. Single differencing between epochs is generally done in an effort to eliminate cycle ambiguities. There are three forms of single differencing techniques between epochs currently in use today: Intermittently Integrated Doppler (IID), Consecutive Doppler Counts (CDC), and Continuously Integrated Doppler (CID). IID uses a technique whereby Doppler count is recorded for a small portion of the observation period, the Doppler count is reset to zero, and then at a later time the Doppler count is restarted during the observation period. CDC uses a technique whereby Doppler count is recorded for a small portion of the observation period, reset to zero, and then restarted immediately and continued throughout the observation period.

b. Double differencing. Double differencing is actually a differencing of two single differences (as detailed in *a* above). There are two general double differencing processing techniques: receiver-time double and receiver-satellite (see Figure 10-2). Double difference processing techniques eliminate clock errors.

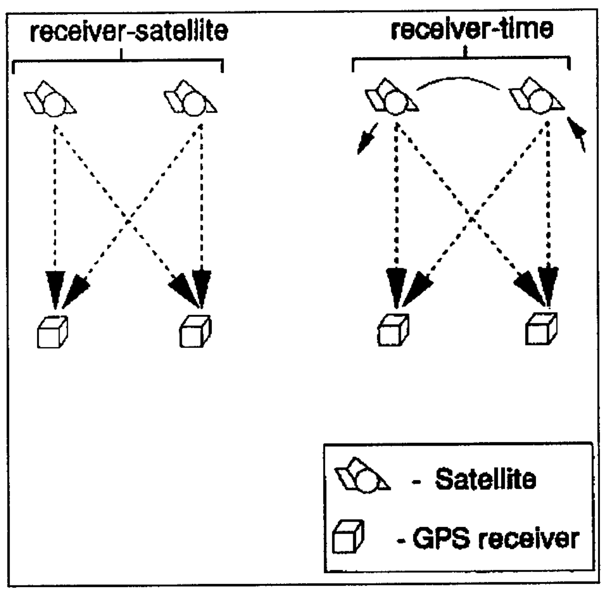


Figure 10-2. Double differencing

(1) Receiver-time double differencing. This technique uses a change from one epoch to the next, in the between-receiver single differences for the same satellite. Using this technique eliminates satellite-dependent integer cycle ambiguities and simplifies editing of cycle slips.

(2) Receiver-satellite double differencing. There are two different techniques that can be used to compute a receiver-satellite double difference. One technique involves using two between-receiver single differences.

This technique also uses a pair of receivers, recording different satellite observations during a survey session and then differencing the observations between two satellites. The second technique involves using two between-satellite single differences. This technique also uses a pair of satellites, but different receivers, and then differences the satellite observations between the two receivers.

c. Triple differencing. There is only one triple differencing processing technique: receiver-satellite-time (see Figure 10-3). All errors eliminated during single- and double-differencing processing are also eliminated during triple differencing. When used in conjunction with carrier beat phase measurements, triple differencing eliminates initial cycle ambiguity. During triple differencing, the data are also automatically edited by the software to delete any data that cannot be solved , so that the unresolved data are ignored during the triple difference solution. This feature is advantageous to the user because of the reduction in the editing of data required; however, degradation of the solution may occur if too much of the data are eliminated during triple differencing.

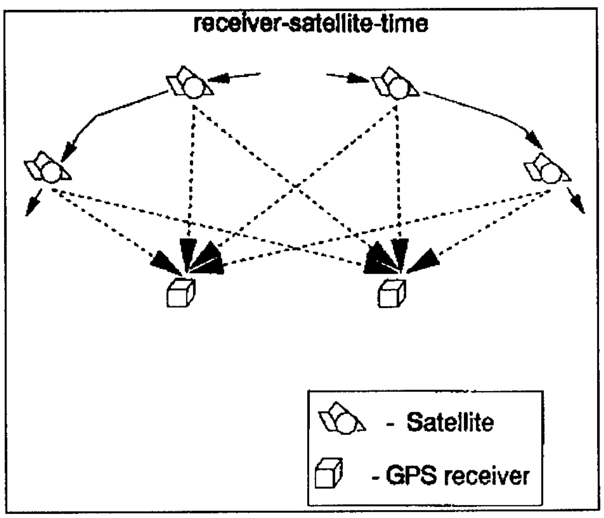


Figure 10-3. Triple differencing

10-5. Baseline Solution by Cycle Ambiguity Recovery

The resultant solution (baseline vector) produced from carrier beat phase observations when differencing resolves cycle ambiguity is called a "fixed" solution. The exact cycle ambiguity does not need to be known to produce a solution; if a range of cycle ambiguities is known, then a "float" solution can be formulated from the range of cycle ambiguities. It is desirable to formulate a fixed solution. However, when the cycle ambiguities cannot be resolved, which occurs when a baseline is between 20 and 65 km in length, a float solution may actually be the best solution. The fixed solution may be unable to determine the correct set of integers (i.e., "fix the integers") required for a solution. Double-differenced fixed techniques can generally be effectively used for positional solutions over short baselines less than 20 km in length. Double differenced float techniques normally can be effectively used for positional solutions for medium-length lines between 20 and 65 km in length.

10-6. Field/Office Data Processing and Verification

a. It is strongly recommended that baselines should be processed daily in the field. This allows the user to identify any problems that may exist. Once baselines are processed, the field surveyor should review each baseline output file. The procedures used in baseline processing are manufacturer-dependent. Certain computational items within the baseline output are common among manufacturers and may be used to evaluate the adequacy of the baseline observation in the field. A list of the triple difference, float double difference, and fixed double difference vectors (*dx-dy-dz*) are normally listed. The geodetic azimuth and distance between the two stations are also listed. The RMS is a quality factor that helps the user determine which vector solution (triple, float, or fixed) to use in an adjustment. The RMS is dependent on the baseline length and the length of time the baseline was observed. Table 10-1 provides guidelines for determining the baseline quality. If the fixed solution meets the criteria in this table, the fixed vector should be used in the adjustment. In some cases the vector passes the RMS test, but after adjustment the vector does not fit into the network. If this occurs, the surveyor should try using the float vector in the adjustments or check to make sure stations were occupied correctly.

b. The first step in data processing is transferring the observation data to a storage device for archiving and/or further processing. Examples of storage devices include a hard disc drive, 5.25-in. disc, 3.5-in. disc, magnetic tape, etc.

c. Once observation data have been downloaded, preprocessing of data can be completed. Pre-processing consists of smoothing/editing the data and ephemeris determination. Smoothing and editing are done to ensure

Table 10-1
Post-processing Criteria

Distance Between Receivers, km	RMS Criteria Formulation (d = distance between receivers)	Formulated RMS Range, cycles	Formulated RMS Range, m
0 - 10	≤(0.02 + (0.004*d))	0.02 - 0.06	0.004 - 0.012
10 - 20	≤(0.03 + (0.003*d))	0.06 - 0.09	0.012 - 0.018
20 - 30	≤(0.04 + (0.0025*d))	0.09 - 0.115	0.018 - 0.023
30 - 40	≤(0.04 + (0.0025*d))	0.115 - 0.14	0.023 - 0.027
40 - 60	≤(0.08 + (0.0015*d))	0.14 - 0.17	0.027 - 0.032
60 - 100	≤0.17	0.17	0.032
> 100	≤0.20	0.20	0.04

Note:

1. These are only general post-processing criteria that may be superseded by GPS receiver/software manufacturer guidelines; consult those guidelines when appropriate.
2. For lines longer than 50 km, dual frequency GPS receivers are recommended to meet these criteria.

data quantity and quality. Activities done during smoothing and editing include determination and elimination of cycle slips; editing gaps in information; and differencing between receivers, satellites, and epochs.

d. Retrieval of post-processed ephemerides may be required depending on the type of receiver used for the survey. Codeless receivers require a post-processed ephemerides file, either that recorded by another GPS receiver concurrent with conduct of the survey or post-processed ephemerides provided by an ephemeris service. Code receivers do not require post-processed ephemerides since they automatically record the broadcast ephemerides during conduct of the survey.

10-7. Post-processing Criteria

Generally, post-processing software will give three solutions: a triple difference, a double-difference fixed solution, and a double-difference float solution. In addition to RDOP as a measurement of the quality of data reduction, methods exist today to gauge the success of an observation session based on data processing done by a differencing process.

a. RMS. RMS is a measurement (in units of cycles or meters) of the quality of the observation data collected during a point in time. RMS is dependent on line length, observation strength, ionosphere, troposphere, and multipath. In general, the longer the line and the more signal interference by other electronic gear, ionosphere, troposphere, and multipath, the higher the RMS will be. A good RMS factor (one that is low, e.g., between 0.01 and 0.2 cycles) may not always indicate good results but is one indication to be taken into account. RMS can generally be used to judge the quality of the data used in the post-processing and the quality of the post-processed baseline vector.

b. Repeatability. Redundant lines should agree to the level of accuracy that GPS is capable of measuring to. For example, if GPS can measure a 10-km baseline to 1 cm $\pm$ 1 ppm, the expected ratio of misclosure would be

$$\frac{0.01\text{ m} + 0.01\text{m}}{10{,}000} = 1{:}500{,}000$$

Repeated baselines should be near the corresponding

$$\frac{1\text{ cm} + 1\text{ ppm}}{\text{baseline}}$$

ratio. See Table 10-2 for an example of repeatability of GPS baselines.

c. Other general information included in a baseline solution.

(1) The following information is typically output from a baseline solution:

(a) Listing of the filename.

(b) Types of solutions (single, double, or triple difference).

Table 10-2
Example of Repeatability of GPS Baselines

Baseline	X	Y	Z	Distance
Line 1	5,000.214	4,000.000	7,680.500	9,999.611
Line 2	5,000.215	4,000.005	7,680.491	9,999.607
Difference	0.001	0.005	0.009	
Ratio = 0.010 / 9,999.6	= 1:967,000			

(c) Satellite availability during the survey for each station occupied.

(d) Ephemeris file used for the solution formulation.

(e) Type of satellite selection (manual or automatic).

(f) Elevation mask.

(g) Minimum number of satellites used.

(h) Meteorological data (pressure, temperature, humidity).

(i) Session time (date, time).

(j) Data logging time (start, stop).

(k) Station information: location (latitude, longitude, height), receiver serial number used, antenna serial number used, ID numbers, antenna height.

(l) RMS.

(m) Solution files: Δx, Δy, Δz between stations, slope distance between stations, Δlatitude, Δlongitude between stations, distance between stations, and Δheight.

(n) Epoch intervals.

(o) Number of epochs.

(2) Sample static baseline formulations from two equipment manufacturers, Ashtech, Inc., (GPPS) and Trimble Navigation (GPSurvey), are shown in Figures 10-4 and 10-5, respectively. The baseline formulations have been annotated with the conventions in (a)-(o) above as an aid in an explanation of the results.

10-8. Field/Office Loop Closure Checks

Post-processing criteria are aimed at an evaluation of a single baseline. In order to verify the adequacy of a group of connected baselines, one must perform a loop closure on the baselines formulated. When GPS baseline traverses or loops are formed, their linear (internal) closure should be determined in the field. If job requirements are less than Third-Order (1:10,000 or 1:5,000), and the internal loop/traverse closures are very small, a formal (external) adjustment may not be warranted.

a. Loop closure software packages. The internal closure determines the consistency of the GPS measurements. Internal closures are applicable for loop traverses and GPS networks. It is required that one baseline in the loop be independent. An independent baseline is observed during a different session or different day. Today, many of the better post-processing software packages come with a loop closure program. Refer to the individual manufacturer post-processing user manuals for a discussion on the particulars of the loop closure program included with the user hardware.

b. General loop closure procedure. If the user post-processing software package does not contain a loop closure program, the user can perform a loop closure as shown below.

(1) List the Δx, Δy, and Δz and length of the baseline being used in a table of the form shown in Table 10-3.

(2) Sum the Δx, Δy, Δz, and distance components for all baselines used in the loop closure. For instance, for the baselines in Table 10-3, the summation would be $\Sigma\Delta x$, $\Sigma\Delta y$, $\Sigma\Delta z$, and Σ*Distances* or $(\Delta x\#1 + \Delta x\#2 + \Delta x\#3)$, $(\Delta y\#1 + \Delta y\#2 + \Delta y\#3)$, $(\Delta z\#1 + \Delta z\#2 + \Delta z\#3)$, and $(\Delta Distance\#1 + \Delta Distance\#2 + \Delta Distance\#3)$, respectively.

(3) Once summation of the Δx, Δy, Δz, and Δ*Distance* components has been completed, the square of each of the summations should be added together and the square root of this sum then taken. This resultant value is the misclosure vector for the loop. This relationship can be expressed in the following manner:

```
Ashtech, Inc. GPPS-L          Program: LINECOMP          Version: 4.5.00
                           Tue Jan 25 10:16:25 1994

Project information
GPS Survey               |25-character project name   [ The | is in column 26. ]
3203C                    |5-character session name
Project information

Known-station parameters
00                       |Receiver identifier used in "LOGTIMES" file
000000                   |Project station number
MANT                     |4-character short name
FIXED STATION            |25-character long name
564 270 DCO PIC__________|25-character comment field
0                        |Position extraction (0=below,1=U-file,2=proj. file)
N  40   2 18.36587       |Latitude deg-min-sec   (g=good;b=bad)
E 285  56 49.57251       |E-Longitude deg-min-sec (g=good;b=bad)
W  74   3 10.42749       |W-Longitude deg-min-sec (g=good;b=bad)
   -12.0807              |Ellipsoidal height  (m) (g=good;b=bad)
     0.0000              |North antenna offset(m)
     0.0000              |East antenna offset (m)
  1.4300   0.0000   0.0000 |Vert antenna offset (m): slant/radius/added_offset
    20.0                 |Temperature (degrees C)
    50.0                 |Humidity (percent)
  1010.0                 |Pressure (millibars)
UMANTC93.320             |Measurement filename (restricted to 24 characters)
Known-station parameters

Unknown-station parameters
00                       |Receiver identifier used in "LOGTIMES" file
000000                   |Project station number
FTM1                     |4-character short name
UNKNOWN STATION          |25-character long name
564 270 DCO PIC__________|25-character comment field
0                        |Position extraction (0=below,1=U-file,2=proj. file)
N  40  18 45.82336       |Latitude deg-min-sec   (g=good;b=bad)
E 285  57 46.72853       |E-Longitude deg-min-sec (g=good;b=bad)
W  74   2 13.27147       |W-Longitude deg-min-sec (g=good;b=bad)
   -20.5991              |Ellipsoidal height  (m) (g=good;b=bad)
     0.0000              |North antenna offset(m)
     0.0000              |East antenna offset (m)
  0.0000   0.0000   0.0000 |Vert antenna offset (m): slant/radius/added_offset
    20.0                 |Temperature (degrees C)
    50.0                 |Humidity (percent)
  1010.0                 |Pressure (millibars)
UFTM1C93.320             |Measurement filename (restricted to 24 characters)
Unknown-station parameters

Run-time parameters
   10                    |First epoch to process
   -1                    |Final epoch to process (-1 = last available)
15.0                     |Elevation cutoff angle (degrees)
1                        |Data to process (0=Wdln;1=L1;2=L2;3=L1c;6=RpdSt)
0.010000                 |Convergence criterion (meters)
00 00 00 00 00 00 00     |Omit these satellites (up to 7)
10                       |Maximum iterations for tlsq and dlsq
00 00 00 00 00 00 00     |Forbidden reference SVs (up to 7)
yes                      |Apply tropo delay correction
Run-time parameters
```

Figure 10-4. Sample static baseline formulation (Ashtech, Inc., GPPS-L) (Sheet 1 of 5)

```
LINECOMP 4.5.00 12/11/92

FIXED U-File from P-Code receiver.
UNKWN U-File from P-Code receiver.

FIXED U-File used BROADCAST orbits.
UNKWN U-File used BROADCAST orbits.

Common start of two UFILES: 1993/11/16 20:23:60.00
Common end   of two UFILES: 1993/11/16 22:00:20.00
    Selected first epoch:  10
    Selected last  epoch:  290
For SV  1 there are    280 triple-difference measurements.
For SV  5 there are    181 triple-difference measurements.
For SV 12 there are    136 triple-difference measurements.
For SV 15 there are    152 triple-difference measurements.
For SV 20 there are    181 triple-difference measurements.
For SV 21 there are    181 triple-difference measurements.
For SV 23 there are    181 triple-difference measurements.
For SV 25 there are    181 triple-difference measurements.
Epoch interval (seconds): 20.000000


THE TRIPLE DIFFERENCE SOLUTION (L1)
Measure of geometry: 0.712832
num_meas =  1192        num_used =  1191         rms_resid = 0.002725(m)
Post-Fit Chisq =  1403.765             NDF      =    11.028


  Sigmax (m):       0.347912
  Sigmay (m):       0.646995
  Sigmaz (m):       0.327369
  x     y     z
x 1.00
y 0.17y 1.00
z 0.12z-0.50z 1.00

del_station: -0.000007 -0.000001 0.000027
     Station1: FIXED STATION                  Station2: UNKNOWN STATION
                (00000)     (MANT)                        (00000)     (FTM1)
 Latitude:  40.03843496  40  2 18.36587           40.31281330  40 18 46.12789
 E-Long  : 285.94710348 285 56 49.57251          285.96293196 285 57 46.55506
 W-Long  :  74.05289652  74  3 10.42749           74.03706804  74  2 13.44494
 E-Height: -12.0807                                -2.8736

 Baseline vector:     -4104.5950     19261.5243     23284.3880

 Mark1 xyz   :  1343513.8259  -4701767.9098   4081246.0717
 Az1 El1 D1  :        2.52867        -0.1200     30496.1759
 E1 N1 U1    :     1350.8948      30465.6429        9.2071
 Mark2 xyz   :  1339409.2309  -4682506.3855   4104530.4598
 Az2 El2 D2  :      182.53888        -0.1546     30496.1759
 E2 N2 U2    :    -1345.4669     -30467.1353       -9.2071

 Double-Difference Epochs:
   Prn:   1  Start epoch:   11  End epoch:  290
   Prn:   5  Start epoch:  110  End epoch:  290
   Prn:  12  Start epoch:  110  End epoch:  249
   Prn:  15  Start epoch:  139  End epoch:  290
   Prn:  20  Start epoch:  110  End epoch:  290
```

Figure 10-4. (Sheet 2 of 5)

```
  Prn:  21  Start epoch:  110  End epoch:  290
  Prn:  23  Start epoch:  110  End epoch:  290
  Prn:  25  Start epoch:  110  End epoch:  290


THE FLOAT DOUBLE DIFFERENCE SOLUTION (L1)
Measure of geometry: 0.195687     Wavelength = 0.190294 (m/cycle)
num_meas =  1200        num_used =  1200         rms_resid = 0.013991(m)
Post-Fit Chisq =   186.429             NDF       =      11.111

Reference SV:  1
  SV      Ambiguity         FIT     Meas       SV      Ambiguity          FIT    Meas
   5          59386.483f   0.054    182        12       -1227312.585f   0.050    138
  15        2121069.816f   0.097    152        20         531426.734f   0.072    182
  21        -184904.908f   0.073    182        23       -1075927.194f   0.062    182
  25         646212.381f   0.093    182

  Sigmax (m):       0.049793
  Sigmay (m):       0.056987
  Sigmaz (m):       0.026423
  SigmaN (cy):      0.283527
  SigmaN (cy):      0.289386
  SigmaN (cy):      0.245180
  SigmaN (cy):      0.217266
  SigmaN (cy):      0.134735
  SigmaN (cy):      0.204750
  SigmaN (cy):      0.196954
  x     y     z     N     N     N     N     N     N     N
x 1.00
y 0.19y 1.00
z 0.08z-0.30z 1.00
N 0.77N 0.74N-0.23N 1.00
N 0.53N 0.90N-0.22N 0.92N 1.00
N-0.81N 0.35N-0.35N-0.27N 0.01N 1.00
N 0.87N 0.27N-0.35N 0.80N 0.58N-0.57N 1.00
N 0.39N-0.52N-0.30N 0.04N-0.24N-0.51N 0.55N 1.00
N 0.70N 0.11N-0.56N 0.62N 0.39N-0.47N 0.91N 0.71N 1.00
N-0.68N-0.57N-0.38N-0.71N-0.70N 0.41N-0.40N 0.35N-0.09N 1.00

del_station: -0.000000 -0.000000 0.000000
     Station1: FIXED STATION                    Station2: UNKNOWN STATION
                (00000)     (MANT)                         (00000)     (FTM1)
 Latitude:  40.03843496  40   2 18.36587          40.31281268  40 18 46.12563
 E-Long   : 285.94710348 285 56 49.57251         285.96293166 285 57 46.55396
 W-Long   :  74.05289652  74   3 10.42749          74.03706834  74  2 13.44604
 E-Height: -12.0807                                 -2.8299

 Baseline vector:     -4104.5984     19261.4419     23284.3633

 Mark1_xyz  :  1343513.8259  -4701767.9098   4081246.0717
 Az1 El1 D1 :        2.52863        -0.1199     30496.1054
 E1 N1 U1   :     1350.8687      30465.5734        9.2508
 Mark2_xyz  :  1339409.2275  -4682506.4679   4104530.4350
 Az2 El2 D2 :      182.53884        -0.1547     30496.1054
 E2 N2 U2   :    -1345.4410     -30467.0660       -9.2508


AMBIGUITY RESOLUTION
                          1          2          3          4
Abs Contrast          0.000      0.000      0.000      0.000
```

Figure 10-4. (Sheet 3 of 5)

```
Contrast                               99.999     100.000     100.000
Change Chi2               318.829     907.189    1231.184    1556.459
Bias S 1: 5                 59387       59385       59387       59387
Bias S 1:12              -1227312    -1227314    -1227312    -1227312
Bias S 1:15               2121070     2121070     2121069     2121071
Bias S 1:20                531427      531426      531427      531427
Bias S 1:21               -184905     -184905     -184905     -184905
Bias S 1:23              -1075927    -1075928    -1075927    -1075927
Bias S 1:25                646212      646213      646212      646213
NDF=127.0000 Chi2=186.4289
                                1           2           3           4
Abs Contrast                0.000       0.000       0.000       0.000
Contrast                               99.999     100.000     100.000
Change Chi2               298.148     843.456    1086.524    1100.925
Bias S 1:12              -1227312    -1227314    -1227313    -1227313
Bias S 1:15               2121070     2121070     2121069     2121071
Bias S 1:20                531427      531426      531427      531426
Bias S 1:21               -184905     -184905     -184905     -184905
Bias S 1:23              -1075927    -1075928    -1075927    -1075928
Bias S 1:25                646212      646213      646212      646213
NDF=127.0000 Chi2=186.4289
                                1           2           3           4
Abs Contrast                0.004       0.000       0.000       0.000
Contrast                               99.986     100.000     100.000
Change Chi2               190.078     526.018     746.284    1076.670
Bias S 1:15               2121070     2121069     2121070     2121069
Bias S 1:20                531427      531427      531426      531426
Bias S 1:21               -184905     -184905     -184905     -184905
Bias S 1:23              -1075927    -1075927    -1075928    -1075928
Bias S 1:25                646212      646212      646213      646212
NDF=127.0000 Chi2=186.4289
                                1           2           3           4
Abs Contrast                4.563       0.000       0.000       0.000
Contrast                              100.000     100.000     100.000
Change Chi2               128.751    2529.042    3851.923    5153.774
Bias S 1: 5                 59387       59388       59387       59387
Bias S 1:12              -1227312    -1227311    -1227311    -1227313
NDF=132.0000 Chi2=376.5065


THE FIXED DOUBLE DIFFERENCE SOLUTION (L1)
Measure of geometry: 0.038900     Wavelength = 0.190294 (m/cycle)
num_meas =  1200          num_used =  1188          rms_resid = 0.021554(m)
Post-Fit Chisq =    435.849            NDF        =     11.000

Reference SV:  1                  Integer Search Ratio =    99.986
  SV      Ambiguity         FIT    Meas       SV     Ambiguity         FIT     Meas
   5        59387.000X    0.066    182        12      -1227312.000X   0.070    138
  15      2121070.000X    0.195    140        20        531427.000X   0.065    182
  21      -184905.000X    0.067    182        23      -1075927.000X   0.080    182
  25       646212.000X    0.176    182

  Sigmax (m):        0.009106
  Sigmay (m):        0.015190
  Sigmaz (m):        0.016909
  x     y     z
x 1.00
y-0.37y 1.00
z 0.40z-0.71z 1.00
```

Figure 10-4. (Sheet 4 of 5)

```
del_station: 0.001087 -0.002400 0.000191
   Station1: FIXED STATION                   Station2: UNKNOWN STATION
             (00000)     (MANT)                        (00000)     (FTM1)
 Latitude:  40.03843496  40   2 18.36587          40.31281315  40 18 46.12733
 E-Long  : 285.94710348 285  56 49.57251         285.96293257 285 57 46.55727
 W-Long  :  74.05289652  74   3 10.42749          74.03706743  74  2 13.44273
 E-Height: -12.0807                                -2.9282

 Baseline vector:     -4104.5533     19261.5680     23284.3397

 Mark1_xyz  :  1343513.8259  -4701767.9098   4081246.0717
 Az1 El1 D1 :       2.52877        -0.1201     30496.1610
 E1 N1 U1   :    1350.9471     30465.6258         9.1525
 Mark2_xyz  :  1339409.2726  -4682506.3418   4104530.4115
 Az2 El2 D2 :     182.53898        -0.1545     30496.1610
 E2 N2 U2   :   -1345.5190    -30467.1180        -9.1525
Tue Jan 25 10:18:17 1994
```

Figure 10-4. (Sheet 5 of 5)

Project Name: ftm1
Processed: Tuesday, January 25, 1994 11:17
WAVE Baseline Processor, version 1.01

Summary Reference Index: 1

Fixed Station: MANT
Antenna Height (meters): 1.430 [True Vertical]
Data file: MANT320C.DAT

Floating Station: FTM1
Antenna Height (meters): 0.000 [True Vertical]
Data file: FTM1320C.DAT

Start Time: 11/16/93 20:21:40 GPS (723 246100)
Stop Time: 11/16/93 22:00:20 GPS (723 252020)
Occupation Time: 0 01:38:40
Measurement Epoch Interval (seconds): 20.00

Solution Type: Receiver/satellite double difference
Fixed integer phase ambiguity
Iono free carrier phase

Solution Acceptability: Passed
Number of Observations / Number Rejected: 1838 / 0 (0.00% of Total Observations)

Baseline Slope Distance (meters): 30496.196

	Forward	Backward
Normal Section Azimuth:	2° 31' 42.850578"	182° 32' 19.610607"
Vertical Angle:	-0° 07' 12.582816"	-0° 09' 16.140268"

Baseline Components (meters):	dn	30466.437	de	1345.414	du	-63.957
	dx	-4104.555	dy	19261.587	dz	23284.370
Standard Deviations:		5.303799E-004		9.044810E-004		8.225305E-004

Aposteriori Covariance Matrix:

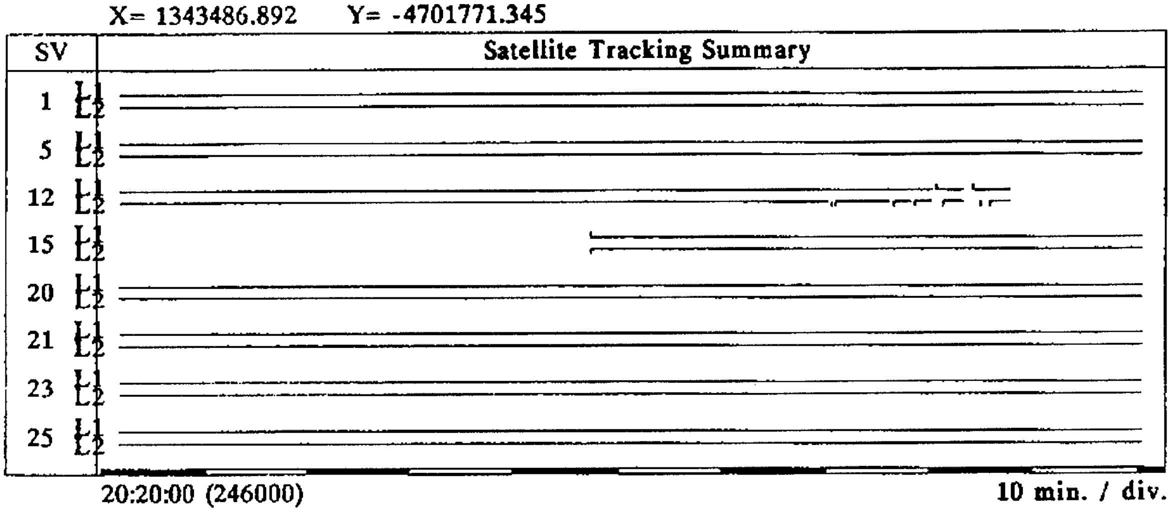
2.813028E-007		
-2.038846E-007	8.180858E-007	
1.759316E-007	-4.827601E-007	6.765565E-007

Reference Variance: 0.633
Variance Ratio 2nd Best/Best Ambiguity Candidate: 28.0
RMS (meters): 0.014

Figure 10-5. Sample static baseline formulation (Trimble Navigation (GP Survey) (Sheet 1 of 3)

Project: ftm1
Processed: Tuesday, January 25, 1994 11:17 WAVE 1.01

Fixed Sta
Position: 40■ 02' 18.244439" N 74■ 03' 11.
X= 1343486.892 Y= -4701771.345



Float Sta
Position: 40■ 18' 46.008533" N 74■ 02' 14.
X= 1339382.336 Y= -4682509.759

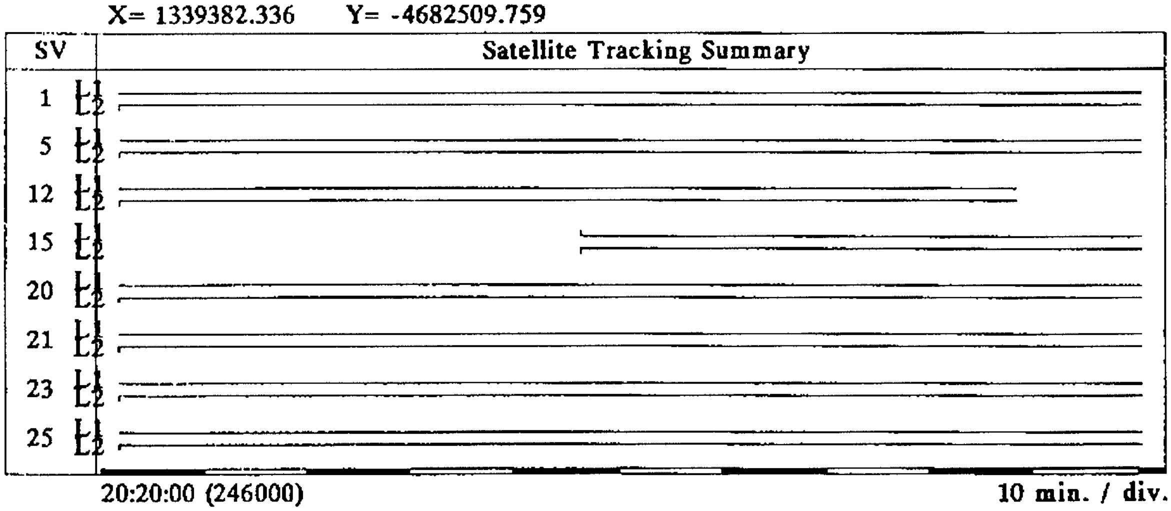


Figure 10-5. (Sheet 2 of 3)

Project: ftm1
Processed: Tuesday, January 25, 1994 11:17 WAVE 1.01

Station si
Shading i

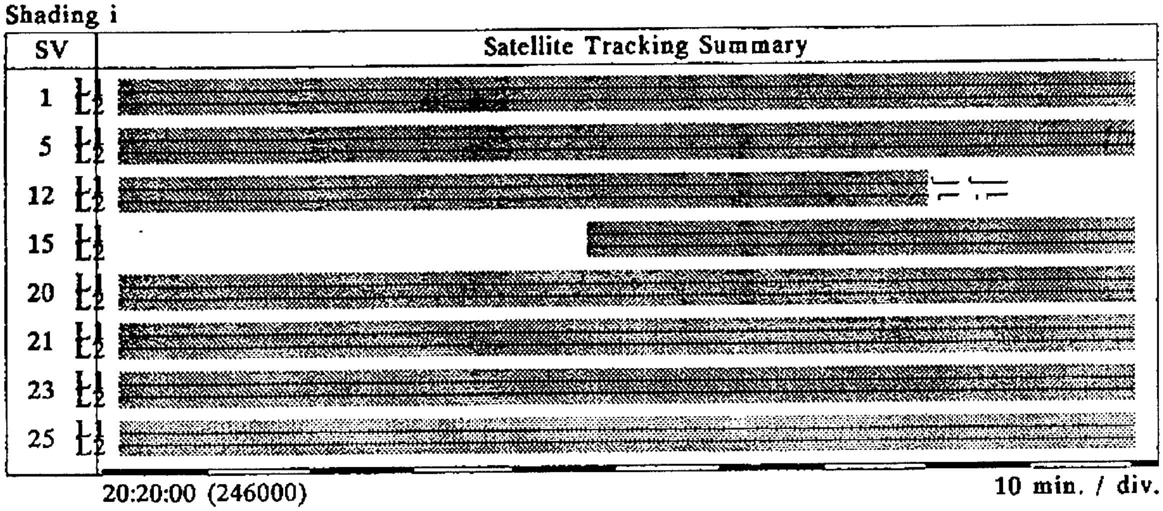


Figure 10-5. (Sheet 3 of 3)

Table 10-3
Loop Closure Procedure

Baseline	Julian Day	Session	Δx	Δy	Δz	ΔDistance
#1	Day	#	Δx #1	Δy #1	Δz #1	Distance #1
#2	Day	#	Δx #2	Δy #2	Δz #2	Distance #2
#3	Day	#	Δx #3	Δy #3	Δz #3	Distance #3

$$m = \sqrt{(\Sigma \Delta x^2) + (\Sigma \Delta y^2) + (\Sigma \Delta z^2)} \qquad (10\text{-}1)$$

where

m = misclosure for the loop

$\Sigma \Delta x$ = sum of all Δx vectors for baselines used

$\Sigma \Delta y$ = sum of all Δy vectors for baselines used

$\Sigma \Delta z$ = sum of all Δz vectors for baselines used

(4) The loop misclosure ratio may be calculated as follows:

$$Loop\ misclosure\ ratio = \frac{m}{L} \qquad (10\text{-}2)$$

where

L = total loop distance (perimeter distance)

(5) The resultant value can be expressed in the following form:

1: Loop Misclosure Ratio

with all units for the expressions being in terms of the units used in the baseline formulations (e.g., m, ft, mm, etc.).

c. Sample loop closure computation. Figure 10-6 shows two loops which consist of four stations. During session A on day 065, three GPS receivers observed the baselines between stations 01, 02, and 03 for approximately 1 hr. The receivers were then turned off and the receiver at station 01 was moved to station 04. The tripod heights at stations 02 and 03 were adjusted. The baselines between stations 02, 03, and 04 were then observed during session B, day 065. Stations 01 and 04 were known control stations. This provided an independent baseline for both loops.

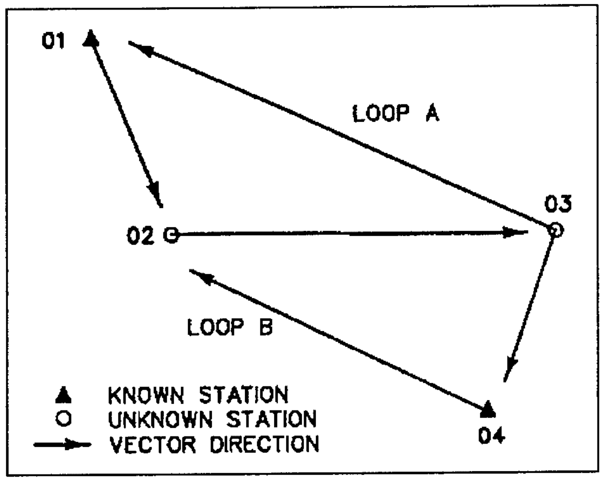


Figure 10-6. Internal loop closure diagram

(1) The closure for loop 01-02-03 is computed with the vectors 01-02 and 01-03, day 065, session A, and the vector 02-03, day 065, session B. The vector 02-03 from session B provides an independent baseline. The loop closure is determined by arbitrarily assigning coordinate values of zero to station 01 (X=0, Y=0, Z=0). The vector from 01-02 is added to the coordinates of station 01. The vector from 02-03, session B, is added to the derived coordinates of station 02. The vector from 03-01 is then added to the station coordinates of 02. Since the starting coordinates of station 01 were arbitrarily chosen as zero, the misclosure is then the computed coordinates of Station 04 (*dx, dy, dz*). The vector data are listed in Table 10-4.

(2) To determine the relative loop closure, the square root of the sum of the squares of the loop misclosures (*mx, my, mz*) is divided into the perimeter length of the loop:

Table 10-4
Vector Data for Stations 01, 02, and 03

Baseline	Julian Day	Session	ΔX	ΔY	ΔZ	ΔDistance
01-02	065	A	-4077.865	-2877.121	-6919.829	8531.759
02-03	065	B	7855.762	-3129.673	688.280	8484.196
03-01	065	A	-3777.910	6006.820	6231.547	9443.869

$$\textit{Loop misclosure ratio} = \frac{(\Delta x^2 - \Delta y^2 - \Delta z^2)^{0.5}}{L} \qquad (10\text{-}3)$$

Where the PD = distance 01-02 + distance 02-03 + distance 03-01, or:

$$PD = 8531.759 + 8484.196 + 9443.869$$

$$= 26{,}459.82$$

And where distance 03-01 is computed from:

$$(-3777.91^2 + 6006.820^2 + 6231.547^2)^{0.5}$$

$$= 9443.869$$

(Other distances are similarly computed.)

Summing the misclosures in each coordinate:

Δx = -4077.865 + 7855.762 - 3777.910 = -0.0135

Δy = -2877.121 - 3129.673 + 6006.820 = +0.0264

Δz = -6919.829 + 688.280 + 6231.547 = -0.0021

then

$$(\Delta x^2 + \Delta y^2 + \Delta z^2)^{0.5} = 0.029$$

Loop misclosure ratio = 0.029/26,459.82

or (approximately) 1 part in 912,000 (1:912,000)

(3) This example is quite simplified; however, it illustrates the necessary mechanics in determining internal loop closures. The values *DX*, *DY*, and *DZ* are present in the baseline output files. The perimeter distance is computed by adding the distances between each point in the loop.

d. External closures. External closures are computed in a similar manner to internal loops. External closures provide information on how well the GPS measurements conform to the local coordinate system. Before the closure of each traverse is computed, the latitude, longitude, and ellipsoid height must be converted to geocentric coordinates (X,Y,Z), using the algorithms given in Chapter 11. If the ellipsoid height is not known, geoid modeling software can be used with the orthometric height to get an approximate ellipsoid height. The external closure will aid the surveyor in determining the quality of the known control and how well the GPS measurements conform to the local network. If the control stations are not of equal precision, the external closures will usually reflect the lower order station. If the internal closure meets the requirements of the job, but the external closure is poor, the surveyor should suspect that the known control is deficient and an additional known control point should be tied into the system.

10-9. Data Management (Archival)

The raw data are defined as data recorded during the observation period. Raw data shall be stored on an appropriate medium (floppy disk, portable hard drive, magnetic tape, etc.). The raw data and the hard copy of the baseline reduction (resultant baseline formulations) shall be stored at the discretion of each USACE Command.

10-10. Flow Diagram

When processing GPS observational data, the progress should generally follow the path shown in Figure 10-7.

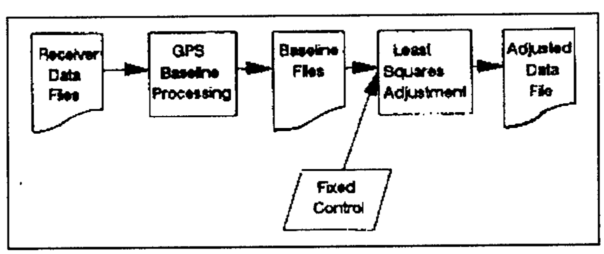


Figure 10-7. GPS data processing flowchart

Chapter 11
Adjustment of GPS Surveys

11-1. General

Differential carrier phase GPS survey observations are adjusted no differently from conventional surveys. Each three-dimensional GPS baseline vector is treated as a separate distance observation and adjusted as part of a trilateration network. A variety of techniques may be used to adjust the observed GPS baselines to fit existing control. Since GPS survey networks often contain redundant observations, they are usually (but not always) adjusted by some type of rigorous least squares minimization technique. This chapter describes some of the methods used to perform horizontal GPS survey adjustments and provides guidance in evaluating the adequacy and accuracy of the adjustment results.

11-2. GPS Error Measurement Statistics

In order to understand the adjustment results of a GPS survey, some simple statistical terms should be understood.

a. Accuracy. Accuracy is how close a measurement or a group of measurements are in relation to a "true" or "known" value.

b. Precision. Precision is how close a group or sample of measurements are to each other. For example, a low standard deviation indicates high precision. It is important to understand that a survey or group of measurements can have a high precision but a low accuracy (i.e., measurements are close together but not close to the known or true value).

c. Standard deviation. The standard deviation is a range of how close the measured values are from the arithmetic average. A low standard deviation indicates that the observations or measurements are close together.

11-3. Adjustment Considerations

a. This chapter deals primarily with the adjustment of horizontal control established using GPS observations. Although vertical elevations are necessarily carried through the baseline reduction and adjustment process, the relative accuracy of these elevations is normally inadequate for engineering and construction purposes. Special techniques and constraints are necessary to determine approximate orthometric elevations from relative GPS observations, as was covered in Chapter 6.

b. The baseline reduction process (described in Chapter 10) directly provides the raw relative position coordinates which are used in a 3D GPS network adjustment. In addition, and depending on the manufacturer's software, each reduced baseline will contain various orientation parameters, covariance matrices, and cofactor and/or correlation statistics which may be used in weighing the final network adjustment. Most least squares adjustments use the accuracy or correlation statistics from the baseline reductions; however, other weighing methods may be used in a least squares or approximate adjustment.

c. The adjustment technique employed (and time devoted to it) must be commensurate with the intended accuracy of the survey, as defined by the project requirements. Care must be taken to prevent the adjustment process from becoming a project in itself.

d. There is no specific requirement that a rigorous least squares type of adjustment be performed on USACE surveys, whether conventional, GPS, or mixed observations. Traditional approximate adjustment methods may be used in lieu of least squares and will provide comparable practical accuracy results.

e. Commercial software packages designed for higher order geodetic densification surveys often contain a degree of statistical sophistication which is unnecessary for engineering survey control densification (i.e., Second-Order or less). For example, performing repeated chi-square statistical testing on observed data intended for 1:20,000 base mapping photogrammetric control may be academically precise but, from a practical engineering standpoint, is inappropriate. The distinction between geodetic surveying and engineering surveying must be fully considered when performing GPS survey adjustments and analyzing the results thereof.

f. Connections and adjustments to existing control networks, such as the NGRS, must not become independent projects. It is far more important to establish dense and accurate local project control than to consume resources tying into First-Order NGRS points miles from the project. Engineering, construction, and property/boundary referencing requires consistent local control with high relative accuracies; accurate connections/references to distant geodetic datums are of secondary importance. (Exceptions might involve projects in support of military operations.) The advent of GPS surveying technology has

provided a cost-effective means of tying previously poorly connected USACE projects to the NGRS, and simultaneously transforming the project to the newly defined NAD 83. In performing (adjusting) these connections, care must be taken not to distort or warp long-established project construction/boundary reference points.

11-4. Survey Accuracy

a. General. The accuracy of a survey (whether performed using conventional or GPS methods) is a measure of the difference between observed values and the true values (coordinates, distance, angle, etc.). Since the true values are rarely known, only estimates of survey accuracy can be made. These estimates may be based on the internal observation closures, such as on a loop traverse, or connections with previously surveyed points assumed to have some degree of reliability. The latter case is typically a traverse (GPS or conventional) between two previously established points, either existing USACE project control or the published NGRS network.

(1) GPS internal accuracies are typically far superior to most previously established control networks (including the NAD 83 NGRS). Therefore, determining the accuracy of a GPS survey based on misclosures with external points is not always valid unless statistical accuracy estimates (i.e., station variance-covariance matrices, distance/azimuth relative accuracy estimates, etc.) from the external network's original adjustment are incorporated into the closure analysis for the new GPS work. Such refinements are usually unwarranted for most USACE work.

(2) Most survey specifications and standards (including USACE) classify accuracy as a function of the resultant relative accuracy between two usually adjacent points in a network. This resultant accuracy is estimated from the statistics in an adjustment, and is defined by the size of a 2D or 3D relative error ellipse formed between the two points. Relative distance, azimuth, or elevation accuracy specifications and classifications are derived from this model, and are expressed either in absolute values (e.g., ±1.2 cm or ±3.5 in.) or as ratios of the propagated standard errors to the overall length (e.g., 1:20,000).

b. Internal accuracy. A loop traverse originating and ending from a single point will have a misclosure when observations (i.e., EDM traverse angles/distances or GPS baseline vectors) are computed forward around the loop back to the starting point. The forward-computed misclosure provides an estimate of the relative or internal accuracy of the observations in the traverse loop, or more correctly, the internal precision of the survey. This is perhaps the simplest method of evaluating the adequacy of a survey. (These point misclosures, usually expressed as ratios, are not the same as relative distance accuracy measures.)

(1) Internal accuracy estimates made relative to a single fixed point are obtained when so-called free, unconstrained, or minimally constrained adjustments are performed. In the case of a single loop, no redundant observations (or alternate loops) back to the fixed point are available. When a series of GPS baseline loops (or network) are observed, then the various paths back to the single fixed point provide multiple position computations, allowing for a statistical analysis of the internal accuracy of not only the position closure but also the relative accuracies of the individual points in the network (including relative distance and azimuth accuracy estimates between these points). The magnitude of these internal relative accuracy estimates (on a free adjustment) determines the adequacy of the control for subsequent design, construction, and mapping work.

(2) Loop traverses are discouraged for most conventional surveys due to potential systematic distance or orientation errors which can be carried through the network undetected. FGCS classification standards for geodetic surveys do not allow traverses to start and terminate at a single point. Such procedures are unacceptable for incorporation into the NGRS network; however, due to many factors (primarily economic), loop traverses or open-ended spur lines are commonly employed in densifying project control for engineering and construction projects. Since such control is not intended for inclusion in the NGRS and usually covers limited project ranges, such practices have been acceptable. Such practices will also be acceptable for GPS surveys performed in support of similar engineering and construction activities.

c. External accuracy. The coordinates (and reference orientation) of the single fixed starting point will also have some degree of accuracy relative to the network in which it is located, such as the NGRS if it was established relative to that system/datum. This "external" accuracy (or inaccuracy) is carried forward in the traverse loop or network; however, any such external variance (if small) is generally not critical to engineering and construction. When a survey is conducted relative to two or more points on an existing reference network, such as USACE project control or the NGRS, misclosures with these fixed control points provide an estimate of the "absolute" accuracy of the survey. This analysis is usually obtained from a final adjustment, usually a fully constrained least squares minimization technique or by

other recognized traverse adjustment methods (Transit, Compass, Crandall, etc.).

(1) This absolute accuracy estimate assumes that the fixed (existing) control is superior to the survey being performed, and that any position misclosures at connecting points are due to internal observational errors and not the existing control. This has always been a long-established and practical assumption and has considerable legal basis in property/boundary surveying. New work is rigidly adjusted to existing control regardless of known or unknown deficiencies in the fixed network.

(2) Since the relative positional accuracies of points on the NGRS are known from the NAD 83 readjustment, and GPS baseline vector accuracy estimates are obtained from the individual reductions, variations in misclosures in GPS surveys are not always due totally to errors in the GPS work. Forcing a GPS traverse/network to rigidly fit the existing (fixed) network usually results in a degradation of the internal accuracy of the GPS survey, as compared with a free (unconstrained) adjustment.

11-5. Internal versus External Accuracy

Classical geodetic surveying is largely concerned with absolute accuracy, or the best-fitting of intermediate surveys between points on a national network, such as the NGRS. Alternatively, in engineering and construction surveying, and to a major extent in boundary surveying, relative, or local, accuracies are more critical to the project at hand. Thus, the absolute NAD 27 or NAD 83 coordinates (in latitude and longitude) relative to the NGRS datum reference are of less importance; however, accurate relative coordinates over a given project reach (channel, construction site, levee section, etc.) are critical to design and construction.

a. For example, in establishing basic mapping and construction layout control for a military installation, developing a dense and accurate internal (or relative) control network is far more important than the values of these coordinates relative to the NGRS.

b. On flood control and river and harbor navigation projects, defining channel points must be accurately referenced to nearby shore-based control points. These points, in turn, directly reference boundary/right-of-way points and are also used for dredge/construction control. Absolute coordinates (NGRS/NAD) of these construction and/or boundary reference points are of less importance.

c. Surveys performed with GPS, and final adjustments thereof, should be configured/designed to establish accurate relative (local) project control; of secondary importance is connection with NGRS networks.

d. Although reference connections with the NGRS are desirable and recommended, and should be made where feasible and practicable, it is critical that such connections (and subsequent adjustments thereto) do not distort the internal (relative) accuracy of intermediate points from which design, construction, and/or project boundaries are referenced.

e. Connections and adjustments to distant networks (i.e., NGRS) can result in mixed datums within a project area, especially if not all existing project control has been tied in. This in turn can lead to errors and contract disputes during both design and construction. On existing projects with long-established reference control, connections and adjustments to outside reference datums/networks should be performed with caution. The impacts on legal property and project alignment definitions must also be considered prior to such connections. (See also paragraph 8-3*d*.)

f. On newly authorized projects, or on projects where existing project control has been largely destroyed, reconnection with the NGRS is highly recommended. This will ensure that future work will be supported by a reliable and consistent basic network, while minimizing errors associated with mixed datums.

11-6. Internal and External Adjustments

GPS-performed surveys are usually adjusted and analyzed relative to their internal consistency and external fit with existing control. The internal consistency adjustment (i.e., free or minimally constrained adjustment) is important from a contract compliance standpoint. A contractor's performance should be evaluated relative to this adjustment. The final, or constrained, adjustment fits the GPS survey to the existing network. This is not always easily accomplished since existing networks often have lower relative accuracies than the GPS observations being fit. Evaluation of a survey's adequacy should not be based solely on the results of a constrained adjustment.

11-7. Internal or Geometric Adjustment

This adjustment is made to determine how well the baseline observations fit or internally close within themselves.

(Other EDM distances or angles may also be included in the adjustment.) It is referred to as a free adjustment. This adjustment provides a measure of the internal precision of the survey.

a. In a simplified example, a conventional EDM traverse which is looped back to the starting point will misclose in both azimuth and position, as shown in Figure 11-1. Classical "approximate" adjustment techniques (e.g., Transit, Compass, Bowditch, Crandall) will typically assess the azimuth misclosure, proportionately adjust the azimuth misclosure (usually evenly per station), recompute the traverse with the adjusted azimuths, and obtain a position misclosure. This position misclosure (in X and Y) is then distributed among all the points on the traverse using various weighing methods (distance, latitudes, departures, etc.). Final adjusted azimuths and distances are then computed from grid inverses between the adjusted points. The adequacy/accuracy of such a traverse is evaluated based on the azimuth misclosure and position misclosure after azimuth adjustment (usually expressed as a ratio to the overall length of the traverse).

b. A least squares adjustment of the same conventional loop traverse will end up adjusting the points similarly to the approximate methods traditionally employed. The only difference is that a least squares adjustment simultaneously adjusts both observed angles (or directions) and distance measurements. A least squares adjustment also allows variable weighting to be set for individual angle/distance observations, which is a somewhat more complex process when approximate adjustments are performed. In addition, a least squares adjustment will yield more definitive statistical results of the internal accuracies of each observation and/or point, rather than just the final closure. This includes estimates of the accuracies of individual station X-Y coordinates, relative azimuth accuracies, and relative distance accuracies.

c. A series of GPS baselines forming a loop off a single point can be adjusted and assessed similarly to a conventional EDM traverse loop described in *a* above (see Figure 11-1). The baseline vector components may be computed (accumulated) around the loop with a resultant 3D misclosure back at the starting point. These misclosures (in X, Y, and Z) may be adjusted using either approximate or least squares methods. The method by which the misclosure is distributed among the intermediate points in the traverse is a function of the adjustment weighting technique.

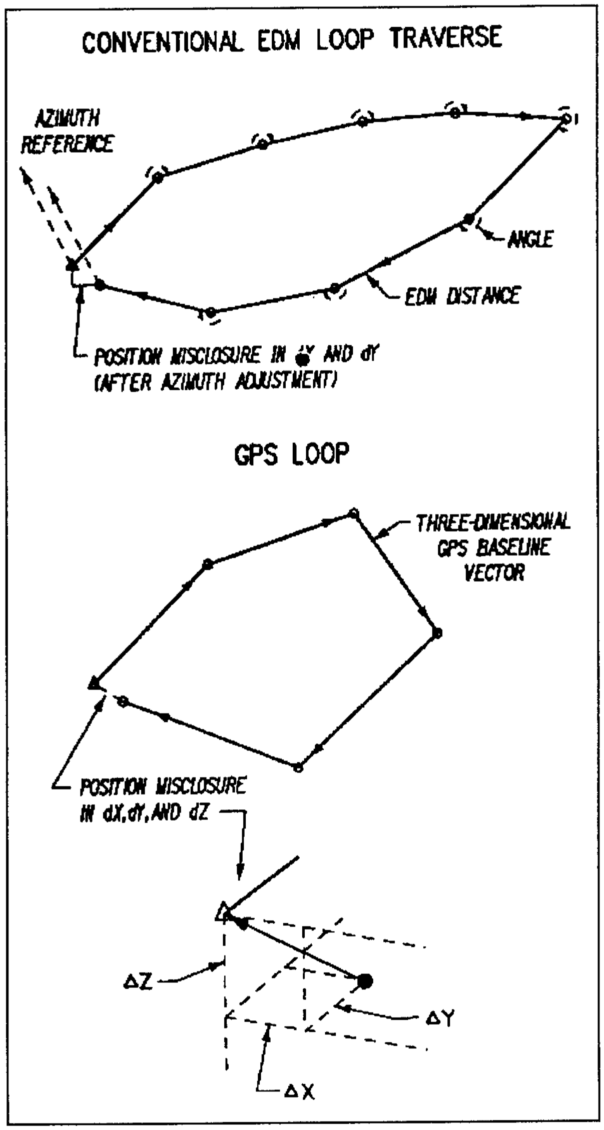


Figure 11-1. Conventional EDM and GPS traverse loops

(1) In the case of a simple EDM traverse adjustment, the observed distances (or position corrections) are weighted as a function of the segment length and the overall traverse length (Compass Rule), or to the overall sum of the latitudes/departures (Transit Rule). Two-dimensional EDM distance observations are not dependent on their direction; that is, a distance's X- and Y-components are uncorrelated.

(2) GPS baseline vector components (in X, Y, and Z) are correlated due to the geometry of the satellite solution; that is, the direction of the baseline vector is significant. Since the satellite geometry is continuously changing, remeasured baselines will have different correlations between the vector components. Such data are passed down from the baseline reduction software for use in the adjustment.

d. The magnitude of the misclosure (i.e., loop closure) of the GPS baseline vectors at the initial point provides an estimate of the internal precision or geometric consistency of the loop (survey). When this misclosure is divided by the overall length of the baselines, an internal relative accuracy estimate results. This misclosure ratio should not be less than the relative distance accuracy classification intended for the survey, per Table 8-1.

(1) For example, if the position misclosure of a GPS loop is 0.08 m and the length of the loop is 8,000 m, then the loop closure is 0.08/8,000 or 1 part in 100,000 (1:100,000).

(2) When an adjustment is performed, the individual corrections/adjustments made to each baseline (so-called residual errors) provide an accuracy assessment for each baseline segment. A least squares adjustment can additionally provide relative distance accuracy estimates for each line, based on standard error propagation between adjusted points. This relative distance accuracy estimate is most critical to USACE engineering and construction work and represents the primary basis for assessing the acceptability of a survey.

11-8. External or Fully Constrained Adjustment

The internal "free" geometric adjustment provides adjusted positions relative to a single, often arbitrary, fixed point. Most surveys (conventional or GPS) are connected between existing stations on some predefined reference network or datum. These fixed stations may be existing project control points (on NAD 27--SPCS 27) or stations on the NGRS (NAD 83). In OCONUS locales, other local or regional reference systems may be used. A constrained adjustment is the process used to best fit the survey observations to the established reference system.

a. A simple conventional EDM traverse (Figure 11-2) between two fixed stations best illustrates the process by which comparable GPS baseline vectors are adjusted. As with the loop traverse described in paragraph 10-8, the misclosure in azimuth and position between the two fixed end points may be adjusted by any type of approximate or least squares adjustment method. Unlike a loop traverse, however, the azimuth and position misclosures are not wholly dependent on the internal errors in the traverse--the fixed points and their azimuth references are not absolute, but contain relative inaccuracies with respect to one another.

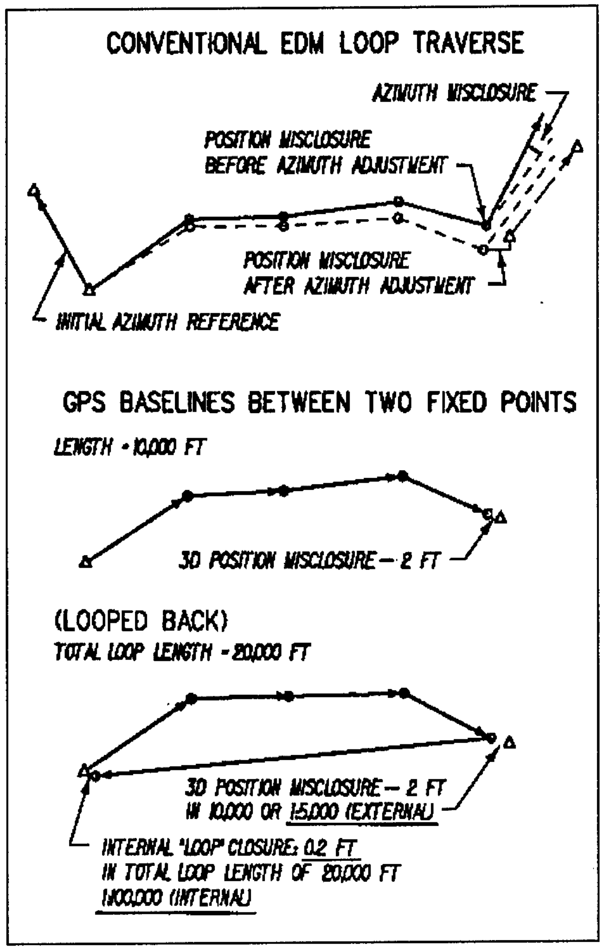


Figure 11-2. Constrained adjustment between two fixed points

b. A GPS survey between the same two fixed points also contains a 3D position misclosure. Due to positional uncertainties in the two fixed network points, this misclosure may (and usually does) far exceed the internal accuracy of the raw GPS observations. As with a conventional EDM traverse, the 3D misclosures may be approximately adjusted by proportionately distributing them over the intermediate points. A least squares adjustment will also accomplish the same thing.

c. If the GPS survey is looped back to the initial point, the free adjustment misclosure at the initial point may be compared with the apparent position misclosure with the other fixed point. In Figure 11-2, the free adjustment loop misclosure is 1:100,000 whereas the misclosure relative to the two network control points is only 1:5,000. Thus, the internal relative accuracy of the GPS survey is on the order of 1 part in 100,000 (based on the misclosure); if the GPS baseline observations are constrained to fit the existing control, the 0.6-m external misclosure must be distributed among the individual baselines to force a fit between the two end points.

(1) After a constrained adjustment, the absolute position misclosure of 0.6 m causes the relative distance accuracies between individual points to degrade. They will be somewhat better than 1:5,000 but far less than 1:100,000. The statistical results from a constrained least squares adjustment will provide estimates of the relative accuracies between individual points on the traverse.

(2) This example also illustrates the advantages of measuring the baseline between fixed network points when performing GPS surveys, especially when weak control is suspected (as in this example).

(3) Also illustrated is the need for making additional ties to the existing network. In this example, one of the two fixed network points may have been poorly controlled when it was originally established, or the two points may have been established from independent networks (i.e., were never connected). A third or even fourth fixed point would be beneficial in resolving such a case.

d. If the intent of the survey shown in Figure 11-2 was to establish 1:20,000 relative accuracy control, connecting between these two points obviously will not provide that accuracy given the amount of adjustment that must be applied to force a fit. For example, if one of the individual baseline vectors was measured at 600 m and the constrained adjustment applied a 0.09-m correction in this sector, the relative accuracy of this segment would be roughly 1:6,666. This distortion would not be acceptable for subsequent design/construction work performed in this area.

e. Most GPS survey networks are more complex than the simple traverse example in Figure 11-2. They may consist of multiple loops and may connect with any number of control points on the existing network. In addition, conventional EDM, angles, and differential leveling measurements may be included with the GPS baselines, resulting in a complex network with many adjustment conditions.

11-9. Partially Constrained Adjustments

In the previous example of the simple GPS traverse, holding the two network points rigidly fixed caused an adverse degradation in the GPS survey, based on the differences between the free (loop) adjustment and the fully constrained adjustment. Another alternative is to perform a semiconstrained (or partially constrained) adjustment of the net. In a partially constrained adjustment, the two network points are not rigidly fixed but only partially fixed in position. The degree to which the existing network points are constrained may be based on their estimated relative accuracies or, if available, their original adjustment positional accuracies (covariance matrices). Partially constrained adjustments are not practicable using approximate adjustment techniques; only least squares will suffice.

a. For example, if the relative distance accuracy between the two fixed network points in Figure 11-2 is approximately 1:10,000, this can be equated to a positional uncertainty between them. Depending on the type and capabilities of the least squares adjustment software, the higher accuracy GPS baseline observations can be best fit between the two end points such that the end points of the GPS network are not rigidly constrained to the original and two control points but will end up falling near them.

b. Adjustment software will allow relative weighting of the fixed points to provide a partially constrained adjustment. Any number of fixed points can be connected to, and these points may be given partial constraints in the adjustment.

c. Performing partially constrained adjustments (as opposed to a fully constrained adjustment) takes advantage of the inherent higher accuracy GPS data relative to the existing network control, which is traditionally weak on many USACE project areas. Less warping of the GPS data (due to poor existing networks) will then occur.

d. A partial constraint also lessens the need for performing numerous trial-and-error constrained adjustments in attempts to locate poor external control points causing high residuals. Fewer ties to the existing network need be made if the purpose of such ties was to find a best fit on a fully constrained adjustment.

e. When connections are made to the NAD 83, relative accuracy estimates of NGRS stations can be obtained from the NGS. Depending on the type of adjustment software used, these partial constraints may be in the form of variance-covariance matrices, error ellipses, or circular accuracy estimates.

11-10. Approximate Adjustments of GPS Networks

Simply constructed GPS networks used for establishing lower order (i.e., Second-Order and lower) USACE control can be effectively adjusted using approximate adjustment techniques, or adjustments which approximate the more rigorous least squares solution. Although least squares solutions may be theoretically superior to approximate methods, the resultant differences between the adjustments are generally not significant from a practical engineering standpoint.

a. Given the high cost of commercial geodetic adjustment software, coupled with the adjustment complexity of these packages, approximate adjustment methods are allowed for in-house and contracted surveys.

b. In practice, any complex GPS survey network may be adjusted by approximate methods. If the main loop/line closures are good, redundant ties to other fixed network points may be used as checks rather than being rigidly adjusted.

c. In some cases it is not cost-effective to perform detailed and time-consuming least squares adjustments on GPS project control surveys requiring only 1:5,000 or 1:10,000 engineering/construction/boundary location accuracy. If internal loop closures are averaging over 1:200,000, then selecting any simple series of connecting baselines for an approximate adjustment will yield adequate resultant positional and relative distance accuracies for the given project requirements. If a given loop/baseline series of say five points miscloses by 0.01 ft over 1,000 m (1:100,000), a case can be made for not even making any adjustment if a relative accuracy of only 1:5,000 is required between points.

d. Any recognized approximate adjustment method may be used to distribute baseline vector misclosures. The method used will depend on the magnitude of the misclosure to be adjusted and the desired accuracy of the survey. These include the following:

(1) Simple proportionate distribution of loop/line position misclosures among the new station coordinates.

(2) Compass Rule.

(3) Transit Rule.

(4) Crandall Method.

(5) No adjustment. Use raw observations if misclosures are negligible.

e. Approximate adjustments are performed using the 3D earth-centered X-Y-Z coordinates. The X-Y-Z coordinates for the fixed points are computed using the transform algorithms shown in *f* below or obtained from the baseline reduction software. Coordinates of intermediate stations are determined by using the baseline vector component differences (ΔX, ΔY, ΔZ) which are obtained directly from the baseline reductions. These differences are then accumulated (summed) forward around a loop or traverse connection, resulting in 3D position coordinate misclosures at the loop nodes and/or tie points. These misclosures are then adjusted by any of the methods in *d* above. GPS vector weighting is accomplished within the particular adjustment method used; there is no need to incorporate the standard errors from the baseline reductions into the adjustment. Internal survey adequacy and acceptance are performed based on the relative closure ratios, as in conventional traversing criteria (see FGCC 1984). Final local datum coordinates are then transformed back from the X-Y-Z coordinates.

f. Given a loop of baseline vectors between two fixed points (or one point looped back on itself), the following algorithms may be used to adjust the observed baseline vector components and compute the adjusted station geocentric coordinates.

(1) Given: Observed baseline vector components ΔX_i, ΔY_i, ΔZ_i for each baseline i (total of n baselines in the loop/traverse). The 3D length of each baseline is l_i, and the total length of the loop/traverse is L.

(2) The misclosures (dx, dy, and dz) in all three coordinates are computed from:

$$
\begin{aligned}
dx &= X_F + \sum_{i=1}^{i=n} \Delta X_i - X_E \\
dy &= Y_F + \sum_{i=1}^{i=n} \Delta Y_i - Y_E \qquad (11\text{-}1) \\
dz &= Z_F + \sum_{i=1}^{i=n} \Delta Z_i - Z_E
\end{aligned}
$$

Where X_F, Y_F, and Z_F are the fixed coordinates of the starting point and X_E, Y_E, and Z_E are the coordinates of the end point of the loop/traverse. (These misclosures would also be used to assess the internal accuracy of the work.)

(3) Adjustments (δx_i, δy_i, δz_i) to each baseline vector component may be computed using either the Compass Rule:

$$\delta x_i = - dx \left(\frac{l_i}{L} \right) \qquad \delta y_i = - dy \left(\frac{l_i}{L} \right) \qquad \delta z_i = - dz \left(\frac{l_i}{L} \right) \tag{11-2}$$

or the Transit Rule:

$$\delta x_i = - dx \left(\frac{\Delta X_i}{\sum \Delta X_i} \right) \qquad \delta y_i = - dy \left(\frac{\Delta Y_i}{\sum \Delta Y_i} \right) \qquad \delta z_i = - dz \left(\frac{\Delta Z_i}{\sum \Delta Z_i} \right) \tag{11-3}$$

(4) The adjusted vector components are computed from:

$$\Delta X_i^a = \Delta X_i + \delta x_i \qquad \Delta Y_i^a = \Delta Y_i + \delta y_i \qquad \Delta Z_i^a = \Delta Z_i + \delta z_i \tag{11-4}$$

(5) The final geocentric coordinates are then computed by summing the adjusted vector components from Equation 11-4 above:

$$X_i^a = X_F + \Sigma \Delta X_i^a \qquad Y_i^a = Y_F + \Sigma \Delta Y_i^a \qquad Z_i^a = Z_F + \Sigma \Delta Z_i^a \tag{11-5}$$

g. Example of an approximate GPS survey adjustment:

(1) Fixed control points from the U.S. Army Yuma Proving Ground GPS Survey (May 1990) (see Figure 11-3):

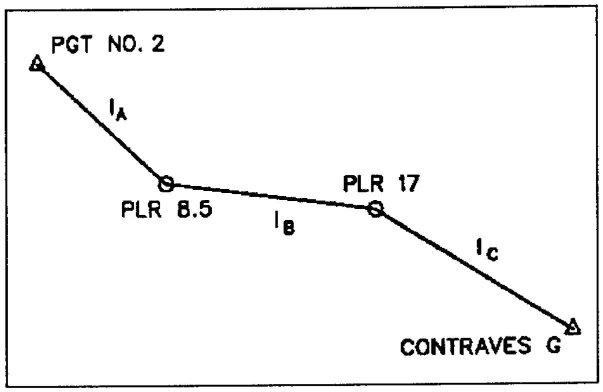


Figure 11-3. Yuma GPS traverse sketch

PGT NO 2:

X_F = (-) 2205 949.0762

Y_F = (-) 4884 126.7921

Z_F = + 3447 135.1550

CONTRAVES G:

X_E = (-) 2188 424.3707

Y_E = (-)4897 740.6844

Z_E = + 3438 952.8159

(XYZ geocentric coordinates were computed from GP-XYZ transform using Equations 11-6 and 11-7 below)

l_a, l_b, l_c = observed GPS baseline vectors (from baseline reductions)

and PLR 8.5 and PLR 17 are the points to be adjusted.

(2) Misclosures in X, Y, and Z (from Equation 11-1):

(-)2205	949.0762	X_F
+3	777.9104	ΔXa
+7	859.4707	ΔX_b
+5	886.8716	ΔXc
-(-)2188	424.3707	X_E

$\underline{dx = (-)\ 0.4528}$

(-)4884	126.7921	Y_F
(-)6	006.8201	ΔY_a
(-)3	319.1092	ΔY_b
(-)4	288.9638	ΔY_c
-(-)4897	740.6844	Y_E

$\underline{dy = (-)\ 1.0008}$

3447	135.1550	Z_F
(-)6	231.5468	ΔZ_a
+	400.1902	ΔZ_b
(-)2	350.2230	ΔZ_c
- 3438	952.8159	Z_E

$\underline{dz = +\ 0.7595}$

(3) Linear 3D misclosure:

$= (0.4528^2 + 1.0008^2 + 0.7595^2)^{1/2} = \underline{1.335\ \text{m}}$

or 1 part in 25,638.2/1.335 = $\underline{1{:}19{,}200}$

(Note: This is a constrained misclosure check, not free)

(4) Compass Rule adjustment:

(a) Compass Rule misclosure distribution:

l_a = 9,443.869		l_a/L = 0.368
l_b = 8,540.955		l_b/L = 0.333
l_c = 7,653.366		l_c/L = 0.299
L = 25,638.190		Σ = 1.000

(b) Compass Rule adjustment to GPS vector components using Equation 11-2:

Vector	δ_x	δ_y	δ_z
A	0.1666	0.3683	(-) 0.2795
B	0.1508	0.3333	(-) 0.2529
C	0.1354	0.2992	(-) 0.2271
	(+0.4528)	(+1.0008)	((-)0.7595) Check

(c) Adjusted baseline vectors (Equation 11-4):

Vector	ΔX^a	ΔY^a	ΔZ^a
A	3778.0770	(-)6006.4518	(-)6231.8263
B	7859.6215	(-)3318.7759	399.9373
C	5887.0070	(-)4288.6646	(-)2350.4501

(d) Final adjusted coordinates (Equation 11-5):

	X^a	Y^a
PGT No. 2	(-)2205 949.0762	(-)4884 126.7921
PLR 8.5	(-)2202 170.9992	(-)4890 133.2439
PLR 17	(-)2194 311.3777	(-)4893 452.0198
Contraves G (Check)	(-)2188 424.3707	(-)4897 740.6844

	Z^a	
PGT No. 2	+3447	135.1550
PLR 8.5	+3440	903.3287
PLR 17	+3441	303.2660
Contraves G (Check)	+3438	952.8159

(e) Adjusted geocentric coordinates are transformed to ϕ, λ, h, using Equations 11-9 through 11-13. Geographic coordinates may then be converted to local SPCS (either NAD 83 or NAD 27) project control using USACE program CORPSCON.

(5) Transit Rule adjustment.

(a) Distribution of GPS vector misclosures using Equation 11-3:

$$\Sigma \Delta X_i = 3777.9104 + 7859.4707 + 5886.8716 = 17{,}524.2527$$

Similarly,

$$\Sigma \Delta Y_i = 13{,}614.8931$$

$$\Sigma \Delta Z_i = 8{,}981.9600$$

$$\delta x_i = -dx \left(\frac{\Delta X_i}{\sum \Delta X_i} \right) = -(-) \frac{0.4528}{17{,}524.2527} \Delta X_i$$

$$= +2.584 \times 10^5 \quad \Delta X_i$$

Similarly,

$$\delta y_i = +7.351 \times 10^5 \, \Delta Y_i$$
$$\delta z_i = (-)8.456 \times 10^5 \, \Delta Z_i$$

(b) Adjustments to baseline vector components using Transit Rule (Equation 11-3):

Vector	δx	δy	δz
A	0.0976	0.4415	(-)0.5269
B	0.2031	0.2440	(-)0.0338
C	0.1521	0.3153	(-)0.1987
(check)	(0.4528)	(1.0008)	(- 0.7595)

(c) Adjusted baseline vectors (Equation 11-4):

Vector	ΔX^a	ΔY^a	ΔZ^a
A	3 778.0080	(-)6 006.3786	(-)6 232.0737
B	7 859.6738	(-)3 318.8652	+ 400.1564
C	5 887.0237	(-)4 288.6485	(-)2 350.4217

(d) Final adjusted coordinates (Equation 11-5):

	X^a	Y^a
PGT No. 2	(-)2 205 949.0762	(-)4884 126.7921
PLR 8.5	(-)2 202 171.0682	(-)4890 133.1707
PLR 17	(-)2 194 311.3944	(-)4893 452.0359
Contraves G (Check)	(-)2 188 424.3707	(-)4897 740.6844

	Z^a
PGT No. 2	+3447 135.1550
PLR 8.5	+3440 903.0813
PLR 17	+3441 303.2377
Contraves G (Check)	+3438 952.8160

(6) Proportionate distribution adjustment method.

(a) Vector misclosures are simply distributed proportionately over each of the three GPS baselines in the traverse:

$$\delta x = -(-)\frac{0.4528}{3} = +0.1509$$

$$\delta y = -(-)\frac{1.0008}{3} = +0.3336$$

$$\delta z = -(-)\frac{0.7595}{3} = (-)\,0.2532$$

Vector	ΔX^a	ΔY^a	ΔZ^a
A	3778.0613	(-) 6006.4865	(-) 6231.8000
B	7859.6216	(-) 3318.7756	+ 399.9370
C	5887.0225	(-) 4288.6302	(-) 2350.4762

(b) Final adjusted coordinates:

	X^a	Y^a
PLR 8.5	(-)2202 171.0149	(-)4890 133.2786
PLR 17	(-)2194 311.3933	(-)4893 452.0542

	Z^a
PLR 8.5	+3440 903.3550
PLR 17	+3441 303.2920

Note: Relatively large horizontal (2D) misclosure (1:23,340) may be due to existing control inadequacies, not poor GPS baseline observations.

(c) Variance between adjusted coordinates yields relative accuracies well in excess of 1:20,000; thus, if project control requirements are only 1:10,000, then any of the three adjustment methods may be used.

The recommended method is the Compass Rule.

Fixed coordinates of PGT No. 2 and CONTRAVES G can be on any reference ellipsoid -- NAD 27 or NAD 83.

11-11. Geocentric Coordinate Conversions

The following algorithms for transforming between geocentric and geographic coordinates can be performed in the field on a Hewlett-Packard-style hand-held calculator.

a. Geodetic to Cartesian coordinate conversion. Given geodetic coordinates on NAD 83 (in ϕ, λ, H) or NAD 27, the geocentric Cartesian coordinates (X, Y, and Z) on the WGS 84, GRS 80, or Clarke 1866 ellipsoid are converted directly by the following formulas.

$$X = (R_N + h)\cos\phi\cos\lambda$$
$$Y = (R_N + h)\cos\phi\sin\lambda \qquad (11\text{-}6)$$
$$Z = \left(\frac{b^2}{a^2}R_N + h\right)\sin\phi$$

where

ϕ = latitude

λ = 360° - λ_W (for CONUS west longitudes)

h = the ellipsoidal elevation. If only the orthometric elevation H is known, then that value may be used.

The normal radius of curvature R_N can be computed from either of the following equations:

$$R_N = \frac{a^2}{\sqrt{a^2\cos^2\phi + b^2\sin^2\phi}} \qquad (11\text{-}7)$$

$$R_N = \frac{a}{\sqrt{1 - e^2\sin^2\phi}} \qquad (11\text{-}8)$$

and

a (GRS 80) = 6,378,137.0 m (semimajor axis)
a (WGS 84) = 6,378,137.0 m
a (NAD 27) = 6,378,206.4 m

b (GRS 80) = 6,356,752.314 1403 m (semiminor axis)
b (WGS 84) = 6,356,752.314 m
b (NAD 27) = 6,356,583.8 m

f (GRS 80) = 1/298.257 222 100 88 (flattening)
f (WGS 84) = 1/298.257 223 563
f (NAD 27) = 1/294.978 698

e^2 (GRS 80) = 0.006 694 380 222 90 (eccentricity squared)
e^2 (WGS 84) = 0.006 694 379 9910
e^2 (NAD 27) = 0.006 768 658

NAD 27 = Clarke Spheroid of 1866
GRS 80 = NAD 83 reference ellipsoid

also

$b = a(1 - f)$

$e^2 = f(2 - f) = (a^2 - b^2) / a^2$

$e'^2 = (a^2 - b^2) / b^2$

b. Cartesian to geodetic coordinate conversion. In the reverse case, given GRS 80 X, Y, Z coordinates, the conversion to NAD 83 geodetic coordinates (ϕ, λ, H) is performed using the following noniterative method (Soler and Hothem 1988):

$$\lambda = \arc\tan\frac{Y}{X} \qquad (11\text{-}9)$$

The latitude ϕ and height h are computed using the following sequence. The initial reduced latitude β_o is first computed:

$$\tan\beta_0 = \frac{Z}{p}\left[(1 - f) + \frac{e^2 a}{r}\right] \qquad (11\text{-}10)$$

where

$$p = \sqrt{X^2 + Y^2}$$
$$e^2 = 2f - f^2$$
$$r = \sqrt{p^2 + Z^2}$$

Directly solving for ϕ and h:

$$\tan\phi = \frac{Z(1 - f) + e^2 a\sin^3\beta_0}{(1 - f)(p - ae^2\cos^3\beta_0)} \qquad (11\text{-}11)$$

$$h^2 = (p - a\cos\beta)^2 + (Z - b\sin\beta)^2 \qquad (11\text{-}12)$$

where the final reduced latitude β is computed from

$$\tan\beta = (1 - f)\tan\phi \qquad (11\text{-}13)$$

c. Transforms between other OCONUS datums may be performed by changing the ellipsoidal parameters a, b, and f to that datum's reference ellipsoid.

d. Example geocentric-geographic coordinate transform.

Geographic to geocentric (ϕ, λ, h to X, Y, Z) transform:

(1) Given any point:

ϕ_N = 35° 27' 15.217"

λ_W = 94° 49' 38.107"

λ = 360° - λ_W = 265.1727481°

h = 100 m (N = 0 assumed)

(2) Given constants (WGS 84):

a = 6,378,137 m b = a(1 - f) = 6,356,752.314

f = 1/298.257223563 e^2 = f(2 - f) = 6.694380 x 11^{-3}

$$R_N = a/(1 - e^2 \sin^2 \phi)^{1/2} = \underline{6{,}385{,}332{,}203}$$
$$X = (R_N + h) \cos \phi \cos \lambda = \underline{(-)437{,}710.553}$$
$$Y = (R_N + h) \cos \phi \sin \lambda = \underline{(-)5{,}182{,}990.319}$$
$$Z = \left(\frac{b^2}{a^2} R_N + H\right) \sin \phi = \underline{+3{,}679{,}090.327}$$

e. Geocentric (X, Y, Z) to geographic (ϕ, λ, H) transform.

Inversing the above X, Y, Z geocentric coordinates:

p = $(X^2 + Y^2)^{1/2}$ = 5,201,440.106

r = $(p^2 + Z^2)^{1/2}$ = 6,371,081.918

$$\beta_o = \tan^{-1} \frac{Z}{p} \left[(1 - f) + \frac{e^2 a}{r}\right] = 35.36295229°$$

$$\tan \phi = \frac{Z(1 - f) + e^2 a \sin^3 \beta_o}{(1 - f)\,(p - ae^2 \cos^3 \beta^o)}$$
$$= 0.712088398$$

ϕ = 35.45422693° = 35° 27' 15.217"

λ = $\tan^{-1}$(Y/X) = 85.17274810° (= 265.17274810°)

λ_W = 360° - λ = 94° 49' 38.107"

β = $\tan^{-1}$ [(1 - f) tan ϕ] = 35.36335663°

$$h^2 = (p - a \cos \beta)^2 + (Z - b \sin \beta)^2$$
$$= (81.458)^2 + (58.004)^2$$

h = 99.999 = 100 m

f. North American Datum of 1927 (Clarke Spheroid of 1866). Given a point with SPCS/Project coordinates on NAD 27, the point may be converted to X, Y, Z coordinates for use in subsequent adjustments.

ϕ_N = 35° 27' 15.217"

λ_W = 94° 49' 38.107" h or H = 100 m

(NAD 27 from SPCS X-Y ϕ,λ conversion using USACE program CORPSCON)

a = 6,378,206.4

b = 6,356,583.8

f = 1/294.978698

e^2 = 0.006768658
(NAD 27/Clarke 1866 Spheroid)

$$R_N = \frac{a}{(1 - e^2 \sin^2 \phi)^{1/2}} = \underline{6{,}392{,}765.205}$$

$$X = (R_N + h) \cos \phi \cos \lambda = (-)\ 438{,}220.073 \text{ m}$$
$$Y = (R_N + h) \cos \phi \sin \lambda = (-)\ 5{,}189{,}023.612 \text{ m}$$
$$Z = \left(\frac{b^2}{a^2} R_N + H\right) \sin \phi = +3{,}733{,}466.852 \text{ m}$$

These geocentric coordinates (on NAD 27 reference) may be used to adjust subsequent GPS baseline vectors observed on WGS 84.

11-12. Rigorous Least Squares Adjustments of GPS Surveys

Adjustment of GPS networks on PC-based software is typically a trial-and-error process for both the free and constrained adjustments. When a least squares adjustment is performed on a network of GPS observations, the adjustment software will provide 2D or 3D coordinate accuracy estimates, variance-covariance matrix data for the adjusted coordinates, and related error ellipse data. Most software will provide relative accuracy estimates (length and azimuth) between points. Analyzing these

various statistics is not easy, and they are also easily misinterpreted. Arbitrary rejection and readjustment in order to obtain a best fit (or best statistics) must be avoided. The original data reject criteria must be established and justified in a final report document.

a. When a series of loops are formed relative to a fixed point or off another loop, different redundant conditions are formed. (This is comparable to loops formed in conventional differential level nets.) These different loops allow forward baseline vector position computations to be made over different paths. From the different routes (loops) formed, different positional closures at a single fixed point result. These variances in position misclosures from the different routes provide additional data for assessing the internal consistency of the network, in addition to checking for blunders in the individual baselines. The number of different paths, or conditions, is partially related to the number of degrees of freedom in the network.

(1) Multiple observed baseline observations also provide additional redundancy or strength to a line or network since they are observed at two distinct times of varying satellite geometry and conditions. The amount of redundancy required is a function of the accuracy requirements of a particular survey.

(2) Performing a free adjustment on a complex network containing many redundancies is best performed using least squares methods. An example of such a network is shown in Figure 11-4. Approximate adjustment methods are difficult to evaluate when complex interweaving networks are involved.

(3) Baseline reduction vector component error statistics are usually carried down into the least squares adjustment; however, their use is not mandatory for lower order engineering surveys. GPS network least squares adjustments can be performed without all the covariance and correlation statistics from the baseline reduction.

(4) In practice, any station on the network can be held fixed for the free adjustment. The selected point is held fixed in all three coordinates, along with the orientation of the three axes and a network scale parameter. Usually one of the higher order points on the existing network is used.

b. Least squares adjustment software will output various statistics from the free adjustment to assist in detecting blunders and residual outliers in the free adjustment. Most commercial packages will display the normalized residual for each observation (GPS, EDM, angle, elevation, etc.), which is useful in detecting and rejecting residual outliers. The variance of unit weight is also important in evaluating the overall adequacy of the observed network. Other statistics, such as tau, chi-square, confidence levels, histograms, etc., are usually not significant for lower order USACE engineering projects, and become totally insignificant if one is not well versed in statistics and adjustment theory. Use of these statistics to reject data (or in reporting results of an adjustment) without a full understanding of their derivation and source within the network adjustment is ill-advised; they should be "turned off" if they are not fully understood.

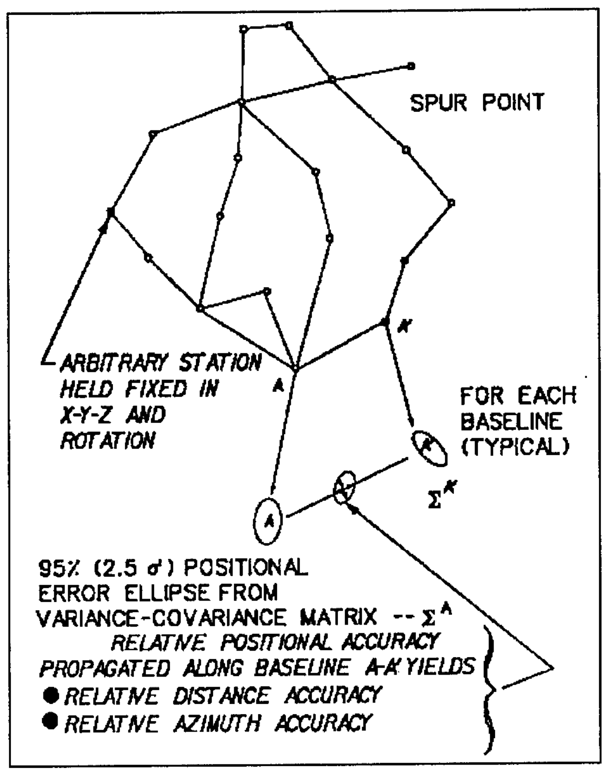


Figure 11-4. Free adjustment of a complex GPS network

c. Relative positional and distance accuracy estimates resulting from a free (unconstrained) geometric adjustment of a GPS network are usually excellent in comparison to conventional surveying methods. Loop misclosures and relative distance accuracies between points will commonly exceed 1:100,000.

d. Relative distance accuracy estimates between points in a network are determined by error propagation

of the relative positional standard errors at each end of the line, as shown in Figure 11-4. Relative accuracy estimates may be derived for resultant distances or azimuths between the points. The relative distance accuracy estimates are those typically employed to assess the free (geometric) and constrained accuracy classifications, expressed as a ratio, such as 1:80,000. Since each point in the network will have its particular position variances, the relative distance accuracy propagated between any two points will also vary throughout the network.

(1) The minimum value (i.e., largest ratio) will govern the relative accuracy of the overall project. This minimum value (from a free adjustment) is then compared with the intended relative accuracy classification of the project to evaluate compliance. However, relative distance accuracy estimates should not be rigidly evaluated over short lines (i.e., less than 500 m).

(2) Depending on the size and complexity of the project, large variances in the propagated relative distance accuracies can result.

(3) When a constrained adjustment is performed, the adequacy of the external fixed stations will have a major impact on the resultant propagated distance accuracies, especially when connections are made to weak control systems. Properly weighted partially constrained adjustments will usually improve the propagated distance accuracies.

e. The primary criteria for assessing the adequacy of a particular GPS survey shall be based on the relative distance accuracy results from a minimally constrained free adjustment, not the fully constrained adjustment. This is due to the difficulty in assessing the adequacy of the surrounding network. Should the propagated relative accuracies fall below the specified level, then reobservation would be warranted.

(1) If the relative distance accuracies significantly degrade on a constrained adjustment (due to the inadequacy of the surrounding network), any additional connections to the network would represent a change in contract scope. A large variance of unit weight usually results in such cases.

(2) If only approximate adjustments are performed, then the relative distance accuracies may be estimated as a function of the loop or position misclosures, or the residual corrections to each observed length. For example, if a particular loop or line miscloses by 1 part in 200,000, then individual baseline relative accuracies can be assumed adequate if only a 1:20,000 survey is required.

f. Most commercial and Government adjustment software will output the residual corrections to each observed baseline (or actually baseline vector components). These residuals indicate the amount by which each segment was corrected in the adjustment. A least squares adjustment minimizes the sum of the squares of these baseline residual corrections.

(1) A number of commercial least squares adjustment software packages are available which will adjust GPS networks using standard IBM PC or PC-compatible computers. Those commonly used by USACE Commands include the following:

(a) TURBO-NET™, Geo-Comp, Inc., distributed by Geodetic Enterprises, Inc., PO Box 837, Odessa, FL 33556, (813) 920-4045.

(b) Geo-Lab™, distributed by GEOsurv, Inc., The Baxter Centre, 6-1050 Baxter Road, Ottawa, Ontario, Canada K2C 3P1, (613) 820-4545.

(c) FILLNET™, distributed by Ashtech, Inc., 1156-C Aster Avenue, Sunnyvale, CA, 94086, (408) 249-1314.

(d) ADJUST™, an adjustment program distributed by the National Geodetic Survey Information Center, Rockville, MD 20852.

(e) TRIMNET™, distruibuted by Trimble Navigation, Inc., 645 North Mary Avenue, P.O. Box 3642, Sunnyvale, CA, 94088-3642, (1-800-TRIMBLE).

(f) STAR*NET™. distributed by STARPLUS SOFTWARE, INC., 460 Boulevard Way, Oakland, CA, 94610, (510) 653-4836).

Annotated sample adjustment outputs from two commercial packages are shown in Figures 11-5 and 11-6.

(2) Relative GPS baseline standard errors can be obtained from the baseline reduction output and, in some software (i.e., Geo-Lab), can be directly input into the adjustment. These standard errors, along with their correlations, are given for each vector component (in X, Y, and Z). They are converted to relative weights in the adjustment. FILLNET allows direct input of vector component standard errors in a $\pm x + y$ ppm form. Correlations are not used in FILLNET. The following typical input (a priori) weighting is commonly used in FILLNET:

```
ADJUSTMENT STATISTICS SUMMARY
NETWORK = FTM1
TIME = Wed Dec 15 18:13:40 1993

                    ADJUSTMENT SUMMARY

Network Reference Factor = 9.09
Chi-Square Test (α = 95%) = FAIL
       Degrees of Freedom = 20.00

            GPS OBSERVATIONS
                Reference Factor = 9.09
                               r = 20.00

GPS Solution    1 Reference Factor =    6.08   r =  2.38
GPS Solution    2 Reference Factor =   14.38   r =  2.66
GPS Solution    3 Reference Factor =    9.91   r =  2.06
GPS Solution    4 Reference Factor =    6.65   r =  2.21
GPS Solution    5 Reference Factor =   11.46   r =  2.13
GPS Solution    6 Reference Factor =    3.37   r =  1.96
GPS Solution    7 Reference Factor =    2.52   r =  2.05
GPS Solution    8 Reference Factor =    5.56   r =  2.10
GPS Solution    9 Reference Factor =   11.65   r =  2.45

                    WEIGHTING STRATEGIES:

     GPS OBSERVATIONS:
          No scalar weighting strategy was used

          No summation weighting strategy was used

          Station Error Strategy:
H.I. error = 0.0010
Tribrach error = 0.0010
```

Figure 11-5. TRIMNET sample adjustment output (Sheet 1 of 6)

```
               COORDINATE ADJUSTMENT SUMMARY
               NETWORK = FTM1
               TIME = Wed Dec 15 18:13:41 1993


Datum = NAD-83
Coordinate System = Geographic
Zone = Global

Network Adjustment Constraints:
  3 fixed coordinates in y
  3 fixed coordinates in x
  3 fixed coordinates in H
  3 fixed coordinates in h

POINT   NAME      OLD COORDS          ADJUST      NEW COORDS          1.96σ

   1 C2PR
         LAT=  40° 25' 35.433030" +0.000000"  40° 25' 35.433030"        FIXED
         LON=  74° 20' 41.879000" +0.000000"  74° 20' 41.879000"        FIXED
      ELL HT=         -29.8100m   +0.0000m           -29.8100m          FIXED
    ORTHO HT=           3.0400m   +0.0000m             3.0400m          FIXED
    GEOID HT=         -32.8500m   +0.0000m           -32.8500m          FIXED

   2 FTM1
         LAT=  40° 18' 46.192066" +0.000003"  40° 18' 46.192069"    0.011390m
         LON=  74° 02' 14.692854" +0.000000"  74° 02' 14.692854"    0.011542m
      ELL HT=         -22.3923m   -0.5752m           -22.9675m      0.016921m
    ORTHO HT=           0.0000m   +0.0000m             0.0000m      NOT KNOWN

   3 MANT
         LAT=  40° 02' 18.425950" +0.000000"  40° 02' 18.425950"        FIXED
         LON=  74° 03' 11.673310" +0.000000"  74° 03' 11.673310"        FIXED
      ELL HT=         -32.1600m   +0.0000m           -32.1600m          FIXED
    ORTHO HT=           1.1500m   +0.0000m             1.1500m          FIXED
    GEOID HT=         -33.3100m   +0.0000m           -33.3100m          FIXED

   4 SIM3
         LAT=  40° 28' 06.064930" +0.000000"  40° 28' 06.064930"        FIXED
         LON=  74° 00' 28.941590" +0.000000"  74° 00' 28.941590"        FIXED
      ELL HT=         -30.5800m   +0.0000m           -30.5800m          FIXED
    ORTHO HT=           2.1000m   +0.0000m             2.1000m          FIXED
    GEOID HT=         -32.6800m   +0.0000m           -32.6800m          FIXED
```

Ftm2
LAT 40° 18' 46.05528"
LON 74° 02' 14.77218"
EH -22.985 m

Figure 11-5. (Sheet 2 of 6)

OBSERVATION ADJUSTMENT SUMMARY
NETWORK = FTM1
TIME = Wed Dec 15 18:13:43 1993

OBSERVATION ADJUSTMENT (Tau = 2.85)

GPS Parameter Group 1 GPS Observations

Azimuth rotation = -0.2339 seconds	1.96σ = 0.0587 seconds
Deflection in latitude = +0.0470 seconds	1.96σ = 0.1005 seconds
Deflection in longitude = +0.5992 seconds	1.96σ = 0.1960 seconds
Network scale = 0.999995521210	1.96σ = 0.000000288587

OBS#	BLK#/ REF#	TYPE	BACKSIGHT/ INSTRUMENT/ FORESIGHT	UDVC/ UDPG/ SBNT	OBSERVED/ ADJUSTED/ RESIDUAL	1.96σ/ 1.96σ/ 1.96σ	TAU
1	1	gpsaz	-**-	-**-	8°12'30.7755"	0.3399"	0.04
	1		FTM1	-**-	8°12'30.7931"	0.1507"	
			SIM3	1	+0.017599"	0.3046"	
2	1	gpsht	-**-	-**-	-7.6308m	0.0495m	0.23
	1		FTM1	-**-	-7.6160m	0.0219m	
			SIM3	1	+0.014794m	0.0444m	
3	1	gpsds	-**-	-**-	17448.3884m	0.0279m	0.34
	1		FTM1	-**-	17448.4006m	0.0126m	
			SIM3	1	+0.012253m	0.0249m	
4	2	gpsaz	-**-	-**-	260°52'34.5985"	0.2105"	0.02
	1		SIM3	-**-	260°52'34.5939"	0.0587"	
			C2PR	1	-0.004628"	0.2022"	
5	2	gpsht	-**-	-**-	+0.8693m	0.0696m	0.19
	1		SIM3	-**-	+0.8516m	0.0282m	
			C2PR	1	-0.017753m	0.0636m	
6	2	gpsds	-**-	-**-	28957.8274m	0.0312m	0.84
	1		SIM3	-**-	28957.8638m	0.0084m	
			C2PR	1	+0.036478m	0.0300m	
7	3	gpsaz	-**-	-**-	8°12'30.5976"	0.3100"	0.50
	1		FTM1	-**-	8°12'30.7931"	0.1507"	
			SIM3	1	+0.195536"	0.2710"	
8	3	gpsht	-**-	-**-	-7.6089m	0.0316m	0.21
	1		FTM1	-**-	-7.6160m	0.0219m	
			SIM3	1	-0.007130m	0.0228m	
9	3	gpsds	-**-	-**-	17448.4119m	0.0265m	0.33
	1		FTM1	-**-	17448.4006m	0.0126m	
			SIM3	1	-0.011284m	0.0233m	
10	4	gpsaz	-**-	-**-	182°32'19.4314"	0.1863"	0.29
	1		FTM1	-**-	182°32'19.3636"	0.0963"	
			MANT	1	-0.067829"	0.1595"	

Figure 11-5. (Sheet 3 of 6)

11	4 gpsht	-**-	-**-	-9.1984m	0.0388m	0.05
	1	FTM1	-**-	-9.1960m	0.0198m	
		MANT	1	+0.002485m	0.0333m	
12	4 gpsds	-**-	-**-	30496.2387m	0.0281m	0.33
	1	FTM1	-**-	30496.2272m	0.0143m	
		MANT	1	-0.011512m	0.0242m	
13	5 gpsaz	-**-	-**-	184°37'13.9839"	0.1196"	0.17
	1	SIM3	-**-	184°37'14.0097"	0.0586"	
		MANT	1	+0.025802"	0.1043"	
14	5 gpsht	-**-	-**-	-1.5901m	0.0399m	0.21
	1	SIM3	-**-	-1.5806m	0.0250m	
		MANT	1	+0.009521m	0.0311m	
15	5 gpsds	-**-	-**-	47890.3245m	0.0284m	0.68
	1	SIM3	-**-	47890.3000m	0.0138m	
		MANT	1	-0.024483m	0.0248m	
16	6 gpsaz	-**-	-**-	330°08'41.8933"	0.1115"	0.05
	1	MANT	-**-	330°08'41.8865"	0.0587"	
		C2PR	1	-0.006765"	0.0947"	
17	6 gpsht	-**-	-**-	+2.4222m	0.0348m	0.23
	1	MANT	-**-	+2.4307m	0.0242m	
		C2PR	1	+0.008509m	0.0250m	
18	6 gpsds	-**-	-**-	49729.7388m	0.0273m	0.07
	1	MANT	-**-	49729.7364m	0.0144m	
		C2PR	1	-0.002441m	0.0232m	
19	7 gpsaz	-**-	-**-	2°31'42.5754"	0.1792"	0.14
	1	MANT	-**-	2°31'42.6064"	0.0960"	
		FTM1	1	+0.031010"	0.1513"	
20	7 gpsht	-**-	-**-	+9.1917m	0.0324m	0.09
	1	MANT	-**-	+9.1951m	0.0198m	
		FTM1	1	+0.003409m	0.0256m	
21	7 gpsds	-**-	-**-	30496.2264m	0.0268m	0.02
	1	MANT	-**-	30496.2272m	0.0143m	
		FTM1	1	+0.000753m	0.0226m	
22	8 gpsaz	-**-	-**-	295°53'30.6165"	0.1904"	0.21
	1	FTM1	-**-	295°53'30.5663"	0.0923"	
		C2PR	1	-0.050255"	0.1665"	
23	8 gpsht	-**-	-**-	-6.7766m	0.0341m	0.33
	1	FTM1	-**-	-6.7642m	0.0224m	
		C2PR	1	+0.012405m	0.0257m	
24	8 gpsds	-**-	-**-	29010.8695m	0.0272m	0.05
	1	FTM1	-**-	29010.8678m	0.0129m	
		C2PR	1	-0.001702m	0.0239m	
25	9 gpsaz	-**-	-**-	295°53'30.6764"	0.2227"	0.37
	1	FTM1	-**-	295°53'30.5663"	0.0923"	
		C2PR	1	-0.110138"	0.2026"	

Figure 11-5. (Sheet 4 of 6)

26	9 gpsht	-**-	-**-	-6.7600m	0.0564m	0.06
	1	FTM1	-**-	-6.7642m	0.0224m	
		C2PR	1	-0.004171m	0.0518m	
27	9 gpsds	-**-	-**-	29010.8399m	0.0319m	0.66
	1	FTM1	-**-	29010.8678m	0.0129m	
		C2PR	1	+0.027863m	0.0291m	

Figure 11-5. (Sheet 5 of 6)

SUMMARY OF COVARIANCES
NETWORK = FTM1
TIME = Wed Dec 15 18:13:45 1993

FROM/ TO	AZIMUTH/ DELTA H	1.96σ 1.96σ	DISTANCE/ DELTA h	1.96σ 1.96σ	HOR PREC
C2PR FTM1	115°41'34" +6.8425m	0.08" 0.0169m	29010.998m -**-	0.0114m -**-	1: 2536313
C2PR MANT	-**- -**-	-**- -**-	-**- -**-	-**- -**-	-**-
C2PR SIM3	-**- -**-	-**- -**-	-**- -**-	-**- -**-	-**-
FTM1 MANT	182°32'20" -9.1925m	0.08" 0.0169m	30496.364m -**-	0.0114m -**-	1: 2675331
FTM1 SIM3	8°12'31" -7.6125m	0.14" 0.0169m	17448.479m -**-	0.0114m -**-	1: 1527827
MANT SIM3	-**- -**-	-**- -**-	-**- -**-	-**- -**-	-**-

Figure 11-5. (Sheet 6 of 6)

```
PROGRAM FILLNET, Version 3.0.00
LICENSED TO: ASHTECH INC.


Fillnet Input File  acts                          40.3    74.1

a =  6378137.000    1/f =  298.2572221   W      Longitude positive WEST

PRELIMINARY COORDINATES:
                            LAT.                LON.         ELEV.     G.H.   CONSTR.

  1           FTM2 40 18 46.25804    74  2 14.14056     47.648    0.000
  2   FFF     MANT 40  2 18.42595    74  3 11.67331    -32.160    0.000
  3   FFF     C2PR 40 25 35.43303    74 20 41.87900    -29.810    0.000
  4   FFF     SIM3 40 28  6.06493    74  0 28.94159    -30.580    0.000
  5           FTM1 40 18 46.19156    74  2 14.69409    -24.152    0.000

GROUP 1, NO. OF VECTORS AND BIAS CONSTRAINTS:

 11      0.000  0.000    0.000  0.000    0.000  0.000    0.000  0.000

VECTORS:
                     DX           DY           DZ        LENGTH    ERROR CODES

FTM1   FTM2      -1.061       -3.124       -3.223        4.612   3 51.0   51.0   2
FTM1   FTM2      -1.059       -3.126       -3.223        4.613   3 51.0   51.0   2
C2PR   MANT   31466.066   -20017.367   -32897.190    49729.603   3 51.0   51.0   3
C2PR   FTM1   27361.521     -755.791    -9612.798    29010.859   3 51.0   51.0   3
MANT   SIM3   -4788.603    30711.771    36432.475    47890.175   3 51.0   51.0   3
MANT   FTM1   -4104.542    19261.593    23284.378    30496.204   3 51.0   51.0   3
SIM3   FTM1     684.063   -11450.182   -13148.091    17448.407   3 51.0   51.0   3
MANT   FTM1   -4104.553    19261.590    23284.377    30496.203   3 51.0   51.0   3
C2PR   SIM3   26677.446    10694.407     3535.282    28957.809   3 51.0   51.0   3
C2PR   FTM1   27361.503     -755.790    -9612.797    29010.842   3 51.0   51.0   3
SIM3   FTM1     684.055   -11450.181   -13148.088    17448.404   3 51.0   51.0   3

 SHIFTS:
   1  -6.254 -14.914 -70.647
   2   0.000   0.000   0.000
   3   0.000   0.000   0.000
   4   0.000   0.000   0.000
   5   0.009   0.035   1.170

ADJUSTED VECTORS, GROUP 1:
                           DX,DY,DZ     V         DN,DE,DU     v        v'

FTM1   FTM2     3213B        -1.060  0.001          -4.214 -0.001    -0.3
                             -3.125 -0.001          -1.876  0.001     0.1
                             -3.223 -0.000          -0.014  0.001     0.2

FTM1   FTM2     3213A        -1.060 -0.001          -4.214  0.001     0.3
                             -3.125  0.001          -1.876 -0.001    -0.1
                             -3.223 -0.000          -0.014 -0.001    -0.2

C2PR   MANT     3203C     31466.069 -0.002      -43116.924  0.019     0.3
                         -20017.389  0.005       24778.270 -0.000    -0.0
                         -32897.156  0.021         -20.476  0.009     0.2

C2PR   FTM1     3203C     27361.531  0.000      -12649.806  0.009     0.2
                           -755.810  0.013       26107.654  0.004     0.1
```

Figure 11-6. FILLNET sample adjustment output (Sheet 1 of 3)

```
                              -9612.775  0.001      53.853 -0.009   -0.2

MANT    SIM3     3203B        -4788.587  0.006   47738.483 -0.015   -0.2
                              30711.758 -0.003    3808.387  0.005    0.1
                              36432.476 -0.015      36.869 -0.006   -0.1

MANT    FTM1     3203B        -4104.538 -0.001   30467.118 -0.010   -0.3
                              19261.579 -0.009    1329.384 -0.003   -0.1
                              23284.381 -0.006      74.329  0.003    0.1

SIM3    FTM1     3203B          684.050 -0.009  -17271.365  0.003    0.1
                             -11450.179 -0.002   -2479.003 -0.009   -0.4
                             -13148.095  0.003      37.460  0.001    0.1

MANT    FTM1     3203C        -4104.538  0.010   30467.118 -0.009   -0.2
                              19261.579 -0.006    1329.384  0.008    0.2
                              23284.381 -0.005      74.329  0.003    0.1

C2PR    SIM3     3203A        26677.482  0.021    4621.559  0.002    0.1
                              10694.369 -0.001   28586.657  0.020    0.6
                               3535.320  0.009      16.393  0.011    0.3

C2PR    FTM1     3203A        27361.531  0.018  -12649.806  0.004    0.1
                               -755.810  0.012   26107.654  0.021    0.6
                              -9612.775 -0.000      53.853 -0.005   -0.1

SIM3    FTM1     3203A          684.050 -0.001  -17271.365 -0.001   -0.1
                             -11450.179 -0.003   -2479.003 -0.002   -0.1
                             -13148.095  0.000      37.460  0.002    0.1

S.E. OF UNIT WEIGHT =     0.278

NUMBER OF -
  OBS. EQUATIONS               33
  UNKNOWNS                     10
  DEGREES OF FREEDOM           23
  ITERATIONS                    0

GROUP  1 ROT. ANGLES (sec.) AND SCALE DIFF. (ppm):

HOR. SYSTEM          0.342  -0.057   0.026   0.101
STD. ERRORS          0.044   0.030   0.025   0.120
XYZ SYSTEM          -0.110   0.178   0.277

ADJUSTED POSITIONS:

                   LAT.               LON.          ELEV.    STD. ERRORS (m)

  1  FTM2    40 18 46.05528   74  2 14.77217   -22.999 0.003 0.004 0.004
  2  MANT    40  2 18.42595   74  3 11.67331   -32.160 0.000 0.000 0.000
  3  C2PR    40 25 35.43303   74 20 41.87900   -29.810 0.000 0.000 0.000
  4  SIM3    40 28  6.06493   74  0 28.94159   -30.580 0.000 0.000 0.000
  5  FTM1    40 18 46.19186   74  2 14.69262   -22.982 0.003 0.003 0.004

ACCURACIES (m):
                                  D. LAT.    D. LON.     VERT.

 FTM1          FTM2               0.001      0.001       0.001
 FTM1          FTM2               0.001      0.001       0.001
```

Figure 11-6. (Sheet 2 of 3)

C2PR	MANT	0.000	0.000	0.000
C2PR	FTM1	0.003	0.003	0.004
MANT	SIM3	0.000	0.000	0.000
MANT	FTM1	0.003	0.003	0.004
SIM3	FTM1	0.003	0.003	0.004
MANT	FTM1	0.003	0.003	0.004
C2PR	SIM3	0.000	0.000	0.000
C2PR	FTM1	0.003	0.003	0.004
SIM3	FTM1	0.003	0.003	0.004

```
*****************************************************************
****                                                         ****
****                 ESTIMATES OF PRECISION                  ****
****                                                         ****
****        Based on the VECTOR ACCURACIES produced by       ****
****                         FILLNET                         ****
****                                                         ****
****      This is a reasonable estimate of the accuracies    ****
****        of the vectors in the network at 1 SIGMA.        ****
****                                                         ****
*****************************************************************
```

VECTOR		LENGTH	PPM(h)	RATIO(h)	PPM(v)	RATIO(v)
FTM1	FTM2	4.613	306.6	1: 3262	216.8	1: 4613
FTM1	FTM2	4.613	306.6	1: 3262	216.8	1: 4613
C2PR	MANT	49729.591	0.0	1: 0	0.0	1: 0
C2PR	FTM1	29010.862	0.1	1: 6837914	0.1	1: 7252715
MANT	SIM3	47890.165	0.0	1: 0	0.0	1: 0
MANT	FTM1	30496.198	0.1	1: 7188001	0.1	1: 7624049
SIM3	FTM1	17448.407	0.2	1: 4112620	0.2	1: 4362102
MANT	FTM1	30496.198	0.1	1: 7188001	0.1	1: 7624049
C2PR	SIM3	28957.832	0.0	1: 0	0.0	1: 0
C2PR	FTM1	29010.862	0.1	1: 6837914	0.1	1: 7252715
SIM3	FTM1	17448.407	0.2	1: 4112620	0.2	1: 4362102
SIM3	FTM1	17448.407	0.2	1: 4112620	0.2	1: 4362102

Figure 11-6. (Sheet 3 of 3)

(a) Fixed: ±3 mm (Lat) ± 5 mm (Long) + 1 ppm ±5 mm (Height) + 1 ppm

(b) Float: ± 6 mm (Lat) ± 10 mm (Long) + 2 ppm ± 10 mm (Height) + 2 ppm

The optimum standard errors shown have been found to be reasonable in standard USACE work where extremely long baselines are not involved. Use of these optimum values is recommended for the first adjustment iteration.

(3) The adequacy of the initial network weighting described in (2) above is indicated by the variance of unit weight (or variance factor in Geo-Lab) which equals the square of the standard error of unit weight (FILLNET). The variance of unit weight should range between 0.5 and 1.5 (or the standard error of unit weight should range between 0.7 and 1.2), with an optimum value of 1.0 signifying realistic weighting of the GPS input observations. A large unit variance (say 5.0) indicates the initial GPS standard errors were too optimistic (low). A low unit variance (say 0.1) indicates the results from the adjustment were better than the assumed GPS baseline precisions used. This unit variance test, however, is generally valid only when a statistically significant number of observations are involved. This is a function of the number of degrees of freedom shown on the adjustment. To evaluate the adequacy of the unit weight, a test such as chi-square in Geo-Lab is performed. Failure of such a test indicates the variance factor statistic may not be statistically valid, including any rejections made using this value.

(4) The input standard errors can easily be juggled in order to obtain a variance of unit weight near 1.0. This trial-and-error method is generally not a good practice. If the input weights are changed, they should not be modified beyond reasonable levels (e.g., do not input a GPS standard error of ±50 + 50 ppm in order to get a good unit variance). If input standard errors are modified, these modifications should be the same for all lines, not just selected ones. Any such modifications of a priori standard errors must be justified in the adjustment report.

(5) Changing the magnitude of the input standard errors/weights will not change the adjusted position or residual results in a free adjustment provided all weight changes are made equally. Although the reference variance will change, the resultant precisions (relative line accuracies) will not change. (This is not true in a constrained adjustment.) Therefore, the internal accuracy of a survey can be assessed based on the free adjustment line accuracies regardless of the initial weighting or variance of unit weight.

(6) The magnitude of the residual corrections shown in the sample adjustments may be assessed by looking for blunders or outliers; however, this assessment should be performed in conjunction with the related normalized residual (FILLNET) or standardized residual (Geo-Lab) statistic. This statistic is obtained by multiplying the residual by the square root of the input weight (the inverse of the square of the standard error). If the observations are properly weighted, the normalized residuals should be around 1.0. Most adjustment software will flag normalized residuals which exceed selected statistical outlier tests. Such flagged normalized residuals are candidates for rejection. A rule-of-thumb reject criterion should be set at three times the standard error of unit weight, again provided that the standard error of unit weight is within the acceptable range given in (3) above. All rejected GPS observations must be justified in the adjustment report clearly describing the test used to remove the observation from the file.

(7) Error ellipses, or 3D error ellipsoids, generated from the adjustment variance-covariance matrices for each adjusted point in Geo-Lab are also useful in depicting the relative positional accuracy. The scale of the ellipse may be varied as a function of the 2D deviation. Usually a 2.45-σ, or 95 percent, probability ellipse is selected for output. The size of the error ellipse will give an indication of positional reliability, and the critical relative distance/azimuth accuracy estimate between two adjacent points is a direct function of the size of these positional ellipses.

(8) The relative distance accuracy estimates (i.e., relative station confidence limits in Geo-Lab and estimates of precision in FILLNET) are used to evaluate acceptability of a survey. This is done using a free adjustment. The output is shown as a ratio (FILLNET) or in parts per million (Geo-Lab). Note that FILLNET uses a 1-σ line accuracy. The resultant ratios must be divided by 2 in order to equate them to FGCS 95 percent criteria. Geo-Lab is set to default to the 95 percent level.

(9) Further details on these statistical evaluations are beyond the scope of this manual. Technical references listed under paragraph A-1 should be consulted.

g. The following is a summary of a network adjustment sequence recommended by the NGS for surveys which are connected with the NGRS:

(1) A minimally constrained 3D adjustment is done initially as a tool to validate the data, check for blunders and systematic errors, and to look at the internal consistency of the network.

(2) A 3D horizontal constrained adjustment is performed holding all previously published horizontal control points fixed and one height constraint. If the fit is poor, then a readjustment is considered. All previous observations determining the readjusted stations are considered in the adjustment.

(3) A fully constrained vertical adjustment is made to determine the orthometric heights. All previously published benchmark elevations are held fixed along with one horizontal position in a 3D adjustment. Geoid heights are predicted using the latest model.

(4) A final free adjustment is performed in which relative accuracy estimates are computed.

11-13. Evaluation of Adjustment Results

A survey shall be classified based on its horizontal point closure ratio, as indicated in Table 11-1 or the vertical elevation difference closure standard given in Table 11-2.

Table 11-1
USACE Point Closure Standards for Horizontal Control Surveys

USACE Classification	Point Closure Standard (Ratio)
Second Order Class I	1:50,000
Second Order Class II	1:20,000
Third Order Class I	1:10,000
Third Order Class II	1: 5,000
4th Order - Construction Layout	1: 2,500 - 1:20:000

Table 11-2
USACE Point Closure Standards for Vertical Control Surveys

USACE Classification	Point Closure Standard (mm)
Second Order Class I	6mm√K
Second Order Class II	8mm√K
Third Order	12mm√K
4th Order - Construction Layout	24mm√K

(√K is square root of distance K in kilometers)

a. Horizontal control standards. The horizontal point closure is determined by dividing the linear distance misclosure of the survey into the overall circuit length of a traverse, loop, or network line/circuit. When independent directions or angles are observed, as on a conventional survey (i.e., traverse, trilateration, or triangulation), these angular misclosures may optionally be distributed before assessing positional misclosure. In cases where GPS vectors are measured in geocentric coordinates, then the 3D positional misclosure is assessed.

(1) Approximate surveying. Approximate surveying work should be classified based on the survey's estimated or observed positional errors. This would include absolute GPS and some differential GPS techniques with positional accuracies ranging from 10 to 150 ft (2DRMS). There is no order classification for such approximate work.

(2) Higher order surveys. Requirements for relative line accuracies exceeding 1:50,000 are rare for most USACE applications. Surveys requiring accuracies of First-Order (1:100,000) or better should be performed using FGCS standards and specifications, and must be adjusted by the NGS.

(3) Construction layout or grade control (Fourth-Order). This classification is intended to cover temporary control used for alignment, grading, and measurement of various types of construction, and some local site plan topographic mapping or photo mapping control work. Accuracy standards will vary with the type of construction. Lower accuracies (1:2,500 - 1:5,000) are acceptable for earthwork, dredging, embankment, beach fill, and levee alignment stakeout and grading, and some site plan, curb and gutter, utility building foundation, sidewalk, and small roadway stakeout. Moderate accuracies (1:5,000) are used in most pipeline, sewer, culvert, catch basin, and manhole stakeout, and for general residential building foundation and footing construction, major highway pavement, and concrete runway stakeout work. Somewhat higher accuracies (1:10,000 - 1:20,000) are used for aligning longer bridge spans, tunnels, and large commercial structures. For extensive bridge or tunnel projects, 1:50,000 or even 1:100,000 relative accuracy alignment work may be required. Vertical grade is usually observed to the nearest 0.005 m for most construction work, although 0.04-m accuracy is sufficient for riprap placement, grading, and small-diameter-pipe placement. Construction control points are typically marked by semi-permanent or temporary monuments (e.g., plastic hubs, P-K nails, wooden grade stakes). Control may be established by short, nonredundant spur shots, using total stations or GPS, or by single traverse runs between two existing permanent control points. Positional accuracy

will be commensurate with, and relative to, that of the existing point(s) from which the new point is established.

b. Vertical control standards. The vertical accuracy of a survey is determined by the elevation misclosure within a level section or level loop. For conventional differential or trigonometric leveling, section or loop misclosures (in millimeters) shall not exceed the limits shown in Table 11-2, where the line or circuit length (K) is measured in kilometers. Fourth-Order accuracies are intended for construction layout grading work. Procedural specifications or restrictions pertaining to vertical control surveying methods or equipment should not be over-restrictive.

11-14. Final Adjustment Reports and Submittals

a. A variety of free and/or constrained adjustment combinations may be specified for a contracted GPS survey. Specific stations to be held fixed may be indicated or a contractor may be instructed to determine the optimum adjustment, including appropriate weighting for constrained points. When fixed stations are to be partially constrained, then appropriate statistical information must be provided--either variance-covariance matrices or relative positional accuracy estimates which may be converted into approximate variance-covariance matrices in the constrained adjustment. All rejected observations will be clearly indicated, along with the criteria/reason used in the rejection.

b. When different combinations of constrained adjustments are performed due to indications of one or more fixed stations causing undue biasing of the data, an analysis shall be made as to a recommended solution which provides the best fit for the network. Any fixed control points which should be readjusted to anomalies from the adjustment(s) should be clearly indicated in a final analysis recommendation.

c. The final adjusted horizontal and/or vertical coordinate values shall be assigned an accuracy classification based on the adjustment statistical results. This classification shall include both the resultant geodetic/Cartesian coordinates and the baseline differential results. The final adjusted coordinates shall state the 95 percent confidence region of each point and the accuracy in parts per million between all points in the network. The datum and/or SPCS will be clearly identified for all coordinate listings.

d. Final report coordinate listings may be required on hard copy as well as on a specified computer media.

e. It is recommended that a scaled plot be submitted with the adjustment report showing the proper locations and designations of all stations established.

Chapter 12
Estimating Costs for Contracted GPS Surveys

12-1. General

Developing cost estimates for GPS surveys is not markedly different from estimating conventional traverse or topographic mapping surveys. Similar production factors directly affect the ultimate cost: number of available GPS receiver units, daily productivity rates, survey accuracy criteria, network redundancy requirements, and required observation time per station. These factors are discussed in detail in previous chapters of this manual. Once the number of GPS observations for a given project has been determined, then the total field survey time and subsequent costs can be computed. Office data reduction and adjustment functions are performed and cost estimated identically to that of conventional survey work. The explanations herein regarding procurement policies and practices describe only the framework within which cost estimates are used. For detailed guidance on procurement policies and practices, refer to the appropriate procurement regulations.

12-2. Hired Labor Surveys

Developing cost estimates for USACE field forces engaged in GPS surveys is performed similarly to that of conventional topographic survey work. Normally, an average daily rate of personnel, travel, per diem, and equipment is established. The GPS instrumentation rental rate is established at the time of purchase and is periodically updated based on actual utilization rates as charged against projects. Fringes, technical indirect, and direct overhead costs are added to a field crew's direct labor. The GPS survey crew rate should be recomputed at least annually, or more often if GPS instrumentation and other plant rental rates change significantly.

12-3. Contracted GPS Survey Services

In accordance with current laws and regulations, GPS surveying services must be procured using qualification-based selection procedures in accordance with PL 92-582 (Brooks Act). GPS services may be included as part of a fixed-price (single project scope) A-E design contract or included as a line item on an indefinite delivery type (IDT) surveying and mapping A-E contract. In some instances, a fixed-scope GPS service contract may be issued. In all cases, GPS surveying services will be negotiated as part of the A-E selection process; therefore, a Government cost estimate for these services must be prepared in advance of formal negotiations with the contractor.

a. Contract types. Fixed-scope GPS service contracts are not common; in most cases, USACE Commands obtain GPS services via the IDT contracting methods. One or more delivery orders may be placed against the IDT contract for specific projects. An overall contract threshold is established--currently \$750,000 per year/contract; thus, the accumulation of individual orders cannot exceed this limit. Individual orders placed against the basic contract are normally limited to \$150,000. The term of an IDT contract is usually set at 1 year; however, an option for year extensions may be authorized. Separate project scopes are written and negotiated for each order. The unit prices established in the basic IDT contract are used as a basis for estimating and negotiating each delivery order. The basic unit prices (U/P) in an IDT contract are established as part of the A-E acquisition and negotiation process; therefore, a Government cost estimate for these services must be prepared in advance of formal negotiations with the contractor. These basic unit prices must adequately represent the anticipated work over the course of the IDT contract--typically a 1-year period. (Separate rates are negotiated for additional option years.) Deficiencies in these unit rates will impact subsequent delivery order negotiations.

b. Unit price basis. A number of methods are used for scheduling GPS services in a fixed-price or IDT contract. The daily rate basis is the cost for a GPS field crew (including all instrumentation, transport, travel, and overhead) over a nominal 8-hr day. This rate method is normally used only on IDT contracts. This pricing method has advantages and drawbacks which need to be considered prior to determining.

(1) A daily crew rate estimating basis is the preferred unit price basis in estimating contracted GPS services for both fixed-price and IDT contracts. It provides the most flexibility for IDT contracts, especially when individual project scopes are expected to vary widely. It is, therefore, considered a more accurate method of determining costs for individual delivery orders. One disadvantage is that a detailed independent government estimate (IGE) must be developed for each delivery order placed against an IDT contract.

(2) The daily rate for a GPS surveying crew must be estimated using the following USACE-directed detailed

analysis method. The crew personnel size, number of GPS receivers deployed, vehicles, etc., must be explicitly indicated in the contract specifications, with differences resolved during negotiations. Options to add additional GPS receiver units (along with personnel and/or transport) must be accounted for in the estimate and unit price schedule. The seven-item breakdown for estimating costs is listed in Table 12-1.

Table 12-1
Factors for Estimating Costs

Item	Description
I	Direct labor or salary costs of GPS survey technicians: includes applicable overtime or other differentials necessitated by the observing schedule.
II	Overhead on Direct Labor.
III	G&A Overhead Costs (on Direct Labor).
IV	Material Costs.[1]
V	Travel and Transportation Costs: crew travel, per diem, etc. Includes all associated costs of vehicles used to transport GPS receivers.[1]
VI	Other Costs: includes survey equipment and instrumentation, such as GPS receivers. GPS receiver costs should be amortized down to a daily rate, based on average utilization rates, expected life, etc. Exclude all instrumentation and plant costs covered under G&A, such as interest.[1]
VII	Profit (To be computed/negotiated on individual delivery orders per EFARS Part 15).

1. Government audit must confirm if any of these direct costs are included in overhead.

(3) A typical contract price schedule using the daily rate basis is shown in Table 12-2. This schedule may be modified as necessary to reflect larger GPS receiver and personnel inventories.

(4) Another advantage of a daily rate basis unit of measure (U/M) is that it is not dependent on the type or order of accuracy of the GPS survey being performed. Either static or kinematic GPS surveys can be estimated and negotiated using this cost basis.

12-4. Verification of Contractor Cost or Pricing Data

Regardless of the cost rate method used, it is essential (but not always required) that a cost analysis, price analysis, and field pricing support audit be employed to verify all cost or pricing data submitted by a contractor, in particular, actual GPS instrumentation utilization rates and reduced costs per day. GPS equipment and instrumentation costs represent a major portion of a field crew's costs, and these cost rates are currently extremely variable. Some GPS operation and maintenance costs may be direct, or portions may be indirectly included in a firm's General and Administrative (G&A) overhead account. In some instances, a firm may lease/rent GPS equipment in lieu of purchase. Rental rates average 10 to 15 percent per month of the purchase cost, or $4,000 to $6,000 per month (1994). Rental would be economically justified only on limited scope projects and if the equipment is deployed on a full-time basis. Whether the GPS equipment is rented or purchased, the primary (and most variable) factor is the GPS equipment's actual utilization rate, or number of actual billing days to clients over a year. Only a detailed audit and cost analysis can establish such rates and justify modifications to the usually rough assumptions used in the IGE. In addition, an audit will establish any nonproductive labor/costs which are transferred to a contractor's G&A. Given the highly changing equipment costs and utilization rates in this new technology, failure to perform a detailed cost analysis and field pricing support audit on contracted GPS services will make the IGE difficult to substantiate.

12-5. Sample Cost Estimate for Contracted GPS Survey Services

The following cost computation is representative of the procedure used in preparing the IGE for an A-E contract. It is developed for a two-receiver, two-man, two-vehicle GPS field survey crew and based on a standard 8-hr workday. Larger crew/receiver size estimates would be performed similarly. Costs and overhead percentages are shown for illustration only--they are subject to considerable geographic-, project-, and contractor-dependent variation (e.g., audited G&A rates could range from 50 to 200 percent). GPS instrumentation rates are approximate (1994) costs. Associated costs for GPS receivers, such as insurance, maintenance contracts, interest, etc., are presumed to be indirectly factored into a firm's G&A overhead account. If not, then such costs must be directly added to the basic equipment depreciation rates shown. Other equally acceptable accounting methods for developing daily costs of equipment may be used. Equipment utilization estimates in an IGE must be subsequently revised (during negotiations) based on actual rates as determined from a detailed cost analysis and field price support audits.

Table 12-2
Daily Rate Basis Contract Schedule

Item	Description	Quan	U/M	U/P	Amount
0001	Registered/Licensed Land Surveyor -- Office	[1]	Day		
0002	Registered/Licensed Land Surveyor	[1]	Day		
0003	Civil Engineering Technician -- Field Party Supervisor (Multiple Crews)	[1]	Day		
0004	Engineering Technician (Draftsman) -- Office	[1]	Day		
0005	Supervisory GPS Survey Technician (Field)	[1]	Day		
0006	Surveying Technician -- GPS Instrumentman/Recorder	[1]	Day		
0007	Surveying Aid -- Rodman/Chainman {Conventional Surveys}	[1]	Day		
0008	[Two][Three][Four][___]- Man GPS Survey Party [___] GPS Receiver(s) [___] Vehicle(s) [___] Computer(s)				
0009	Additional GPS Receiver	[1]	Day		
	{Add Item 0006 Observers as Necessary}	[1]	Day		
0010	Station Monuments [Disk Type] [Construction Materials]	[1]	EA		
0011	Professional Geodesist Computer (office)	[1]	Day		
0012					
0013					

a. *Basic daily crew rate cost estimate.*

(1) Direct Labor.

Supervisory Survey Technician (GPS Observer) @ $20,000/year or $77/day
Survey Technician @ $16,000/year or $62/day

Total direct labor: $139/day

(2) Overhead on direct labor:

@ 30% of direct labor $42/day

(3) G&A overhead:

@ 100% of direct labor $139/day

(4) Materials and supplies: $20/day

(5) Travel and transportation expenses:

Vehicle depreciation:
$17K base @ 5 years @ 220 days/year $15/day

Operation and maintenance (fuel, oil, etc.) $15/day

Total: Two vehicles @ $30/day ea $60/day

Per Diem: average assumed for IDT locale; rate not to exceed published General Services Administration (GSA)/Joint Travel Regulation (JTR) levels

Total: Two men @ $50/day each $100/day

(6) Other costs:

(Miscellaneous survey instrumentation/equipment, tools and equipment (T&E), etc., normally included in G&A overhead.)

GPS receivers (2 each) plus 386-based field computer

Receivers: 2 @ $20K ea	$40,000
Computer + software:	$10,000
Total:	$50,000

5-year depreciation base --
assumed average utilization
of 200 days per year with
maintenance included in G&A rate

Total: $50K @ 5 years @ $200/day) $50/day

(7) Profit: Profit is not computed on the basic contract but is determined for each separate order based on the guidance contained in Part 15 of the EFARS.

Total Estimated Rate:	$550/day

b. Additional GPS receiver.

Direct Labor (Survey Technician)	$62/day
Overhead on direct labor @ 30%	$19/day
G&A @ 100%	$62/day
Material and supplies	$5/day
Travel and transportation:	
Vehicle	$30/day
Per diem	$50/day
Other costs: GPS Receiver	
One receiver $20K @ 5 years @ 200 days/year	$20/day
Total:	$248/day

c. Travel and per diem. The contract schedule must equitably account for actual travel and per diem expenses if a constant temporary duty locale is not involved, or if the per diem rate varies considerably from that estimated for an IDT contract. Some USACE Commands include crew per diem as a separate line item on the schedule or develop a schedule containing local and travel crew rates.

d. Delivery orders. Since unit prices (either daily rates or work unit rates) have been established in the basic contract, each such delivery order is negotiated strictly for effort. The negotiated fee on a delivery order is then a straight mathematical procedure of multiplying the agreed-upon effort (time or unit of measure quantity) against the unit prices, plus an allowance for profit. Thus, an IGE is required for each order placed, along with a detailed profit computation, documented records of negotiations, etc. The scope is attached to a DD 1155 order placed against the basic contract. The process for estimating the time to perform any particular survey function, in a given project, is totally dependent upon the knowledge and personal field experience of the Government estimator.

Appendix A
References

A-1. Required Publications

Public Law 92-582
Public Law 92-582 (86 STAT. 1278), Public Buildings-Selection of Architects and Engineers

EP 25-1-1
Index of Publications, Forms, and Reports

EM 1110-1-1000
Photogrammetric Mapping

EM 1110-1-1002
Survey Markers and Monumentation

EM 1110-1-1004
Deformation Monitoring and Control Surveying

EM 1110-2-1003
Hydrographic Surveying

[1]CW 01332
Civil Works Construction Guide Specifications for Survey Markers and Monumentation

[1]CW 16701
Civil Works Construction Guide Specifications for Procurement of NAVSTAR Global Positioning System (GPS) and Related Instrumentation/Equipment

[1]CW 16702
Civil Works Construction Guide Specifications for Procurement of Real-Time Differential NAVSTAR Global Positioning System (DGPS)

American Society for Photogrammetry and Remote Sensing 1989
American Society for Photogrammetry and Remote Sensing. 1989. "ASPRS Accuracy Standards for Large-Scale Maps," *Photogrammetric Engineering and Remote Sensing*, 1068 and 1070.

[1]Reference published by Department of Army and available through USACE Command Information Management Office sources.

A-2. Related Publications

Section I
Documents Available from NGS

The National Geodetic Survey (NGS) performs research and development into precise positioning using GPS. NGS publishes the following publications and papers which discuss GPS and may be of help to the surveyor. The surveyor can inquire about the availability of these documents by contacting NOAA, National Geodetic Information Center, 1315 East West Highway, Silver Spring, MD, 20910.

Bossler and Challstrom 1985
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Hothem, L. D., and Fronczek, C. J. 1983. "Report on test and demonstration of macrometer model V-1000 interferometric surveyor," Federal Geodetic Control Committee.

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Kass, W. G., and Dulaney, R. 1986. *Procedures for processing GPS phase observations at the National Geodetic Survey.*

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Lucas, J. R., and Mader, G. L. 1988. *Recent advances in kinematic GPS photogrammetry.*

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Mader and Abell 1985
Mader, G. L., and Abell, M. D. 1985. *A comparison between global positioning system and very long baseline interferometry surveys in Alaska and Canada.*

Milbert 1985a
Milbert, D. G. 1985a. *Application of the variance factor test to a global positioning system survey.*

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Milbert, D. G. 1985b. *Preliminary analysis of an operational global position system control survey.*

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Remondi, B. W. 1984. "Using the global positioning system (GPS) phase observable for relative geodesy: modeling, processing, and results," Ph.D diss., University of Texas.

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Remondi, B. W. 1985c. "Performing centimeter-level surveys in seconds with GPS carrier phase: initial results," NOAA Technical Memorandum NOS NGS-43, National Oceanic and Atmospheric Administration.

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Zilkoski, David B., and Hothem, Larry D. 1989. "GPS satellite surveys and vertical control," *Journal of Surveying Engineering.*

Section II
Other Sources

There are also several books and relatively inexpensive publications published by companies and agencies other than NOAA that may be used as general reference sources on GPS:

Burkhard, Richard K., et al. 1983. "Geodesy for the Layman," Defense Mapping Agency (DMA). Available from DMA, Aerospace Center, St. Louis AFS, MO 63118. This text presents the basic principles of geodesy in an elementary form. The formation of geodetic datums is introduced, and the necessity of connecting or joining datums is discussed. Methods used to connect independent geodetic systems to a single world reference system are discussed including the role of gravity data. There is also a discussion of satellite and related technological applications to geodesy and the World Geodetic System.

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Trimble Navigation, Ltd., 1989, 1991, 1992
"GPS: A guide to the next utility," 1989, "GPS: field surveyor's guide, a field guidebook to static surveying," 1991, and "GPS: field surveyor's guide, a field guidebook for dynamic surveying," 1992. Available from Trimble Navigation, Ltd., 645 North Mary Avenue, Sunnyvale, CA 94088-3642. Telephone: (408) 730-2900. A fine basic overview of GPS, its operation, and processing detail.

Appendix B
Glossary

B-1. Abbreviations

A-E . . . . Architect-Engineer
A-S . . . . Anti-Spoofing
ASPRS . . . . American Society for Photogrammetry and Remote Sensing
BIH . . . . Bureau International Heure
C/A-code . . . . Coarse Acquisition Code (for additional information, see paragraph B-2)
CDC . . . . Consecutive Doppler Counts
CDMS . . . . Continuous Deformation Monitoring System
CEP . . . . circular error probable
CID . . . . Continuously Integrated Doppler
CONUS . . . . Continental United States
CTP . . . . Conventional Terrestrial Pole
CW . . . . Civil Works
DGPS . . . . Differential GPS
DoD . . . . Department of Defense
DOP . . . . Dilution of Precision (for additional information, see paragraph B-2)
E&D . . . . engineering and design
ECC . . . . estimated construction cost
ECDIS . . . . Electronic Chart Display Information System
ECEF . . . . earth centered earth fixed
EDM . . . . electronic distance measurement
EFARS . . . . Engineer Federal Acquisition Regulation Supplement
FGCC . . . . Federal Geodetic Control Committee
FGCS . . . . Federal Geodetic Control Subcommittee
FRNP . . . . Federal Radio Navigation Plan
FY . . . . Fiscal Year
G&A . . . . General & Administrative (overhead)
GCP . . . . GPS Controlled Photogrammetry
GDOP . . . . Geometric dilution of precision (for additional information, see *Dilution of Precision* in paragraph B-2)
GIS . . . . Geographic Information System
GPS . . . . Global Positioning System (for additional information, see paragraph B-2)
GRS 80 . . . . Geodetic Reference System of 1980 reference ellipsoid (for additional information, see *Ellipsoid* in paragraph B-2)
HARNS . . . . High Accuracy Reference Networks
HDOP . . . . Horizontal dilution of precision (for additional information, see *Dilution of Precision* in paragraph B-2)
HI . . . . height of instrument
IDT . . . . indefinite delivery type
IGE . . . . independent government estimate
IGLD 55 . . . . International Great Lakes Datum of 1955 (for additional information, see *Datum* in paragraph B-2)
IGLD 85 . . . . International Great Lakes Datum of 1985
IID . . . . Intermittently Integrated Doppler (for additional information, see *Integrated Doppler* in paragraph B-2)
JPO . . . . Joint Program Office
MRSE . . . . mean radial spherical error
MSC . . . . Major Subordinate Command
NAD 27 . . . . North American Datum of 1927 (for additional information, see *Datum* in paragraph B-2)
NAD 83 . . . . North American Datum of 1983 (for additional information, see *Datum* in paragraph B-2)
NATO . . . . North Atlantic Treaty Organization
NAVD 88 . . . . North American Vertical Datum of 1988
NAVSTAR . . . . . . NAVigation Satellite Timing and Ranging
NGRS . . . . National Geodetic Reference System
NGS . . . . National Geodetic Survey
NGVD 29 . . . . National Geodetic Vertical Datum of 1929 (for additional information, see *Datum* in paragraph B-2)
NMEA . . . . National Maritime Electronics Association
NOAA . . . . National Oceanic and Atmospheric Administration
NOS . . . . National Ocean Service
OCONUS . . . . Outside the Continental United States
OTF . . . . On-The-Fly
PC . . . . personal computer
P-code . . . . Precise Code (for additional information, see paragraph B-2)

PDOP . . . . Positional Dilution of Precision (for additional information, see *Dilution of Precision* in paragraph B-2)
PLGR . . . . precise lightweight GPS receiver
PPS . . . . Precise Positioning Service (for additional information, see paragraph B-2)
PRC . . . . pseudo-range correction
PRN . . . . Pseudo-random noise
RINEX . . . . Receiver INdependent EXchange
RDOP . . . . Relative Dilution of Precision (for additional information, see *Dilution of Precision* in paragraph B-2)
RMS . . . . root mean square
RTCM . . . . Radio Technical Commission for Maritime Services
RTK . . . . Real-Time Kinematic
S/A . . . . selective availability (for additional information, see paragraph B-2)
SEP . . . . spherical error probable
SPCS . . . . State Plane Coordinate System (for additional information, see *Datum* in paragraph B-2)
SPCS 27 . . . . State Plane Coordinate System of 1927 (for additional information, see *Datum* in paragraph B-2)
SPS . . . . Standard Positioning Service (for additional information, see paragraph B-2)
TBM . . . . temporary benchmark
3D . . . . three-dimensional
2D . . . . two-dimensional
2DRMS . . . . two standard deviation root mean square
U/M . . . . unit of measure
U/P . . . . unit price
UERE . . . . user equivalent range error (for additional information, see paragraph B-2)
USACE . . . . U.S. Army Corps of Engineers
USATEC . . . . U.S. Army Topographic Engineering Center
USCG . . . . U.S. Coast Guard
USGS . . . . U.S. Geological Survey
UTC . . . . Universal Time Coordinated
VDOP . . . . Vertical dilution of precision (for additional information, see *Dilution of Precision* in paragraph B-2)
WGS 84 . . . . World Geodetic System of 1984 reference ellipsoid (for additional information, see *Ellipsoid* in paragraph B-2)

B-2. Terms

Absolute Positioning
The unique ability of a GPS receiver to produce positional values without another receiver for reference.

Ambiguity
The unknown number of whole carrier wavelengths between the satellite and the receiver. Also called **cycle ambiguity**.

Anti-spoofing (A-S)
An encryption technique developed by the U.S. Department of Defense (DoD) that when implemented, denies access to the P-code by any unauthorized users. With anti-spoofing on, the user will need a DoD-issued "key" in order to gain access to the P-code.

Anywhere Fix
Receiver with unique ability to calculate positions without being given an approximate location and time.

Apogee
The point in the orbit of a satellite about the earth that is the greatest distance from the center of the earth.

Auto-correlation
In reference to code, a plot of the scaler product of the noise sequence with a delayed copy of itself.

Bandwidth
A measure of the width of the frequency spectrum of a signal expressed in Hertz.

Baseline
The resultant three-dimensional vector V between any two stations from which simultaneous GPS data have been collected and processed. Generally given in earth-centered Cartesian coordinates where:

$$V = (\Delta x, \Delta y, \Delta z)$$

Beat Frequency
Either of the two additional frequencies obtained when two signals of two frequencies are mixed, equal to the sum or difference of the original frequencies.

Binary Biphase Modulation
Phase changes on a constant frequency carrier of either 0 or 180 deg. These represent the binary digits 0 and 1, respectively.

Binary Code
A system used in communication where selected strings of 0's and 1's are assigned definite meanings.

Binary Pulse Code Modulation
A two-state pulse modulation using a string of binary numbers or codes. The coding is generally represented by 1 and 0 with definite meanings attached to each.

Broadcast Ephemeris
The ephemeris broadcast by the GPS satellites.

C/A-Code
The standard Coarse/Acquisition GPS code, sometimes referred to as the Clear Access Code, also known as the S- or Standard Code. This code contains a sequence of 1,023 pseudo-random binary biphase modulations on the GPS carrier at a chipping rate of 1.023 MHz, thus having a period of 1 ms.

Carrier
A high-frequency radio wave having at least one characteristic (frequency, amplitude, or phase) which may be varied by modulation from an accepted value. In general, the carrier wavelength is much shorter than the wavelength of the codes.

Carrier Beat Phase
The difference between the phase of the incoming Doppler shifted satellite carrier signal and the phase of the nominally constant reference frequency generated in the receiver.

Carrier Frequency
The frequency of the unmodulated fundamental output of a radio transmitter.

Carrier Phase
The phase measurement of the carrier wave. The percentage value is usually converted to millimeters.

Cartesian/Geocentric Coordinates
A system of defining position which has its origin at the center of the earth with the x- and y-axes in the plane of the equator. Typically, the x-axis passes through the meridian of Greenwich, and the z-axis coincides with the earth's axis of rotation. The three axes are mutually orthogonal and form a right-handed system.

Channel
A channel of a GPS receiver consists of the hardware and the software to track the signal from one satellite at one of the two carrier frequencies.

Chip
a. The minimum transition time interval for individual bits of either a 0 or a 1 in a binary pulse code, usually transmitted in a pseudo-random sequence. b. A tiny square piece of thin semiconductor material on which an integrated circuit is formed or to be formed.

Clock Bias
Difference between clock's indicated time and true universal time.

Code
A system for representing information, together with rules for using the system.

Codeless Receiver
An instrument that does not require a knowledge of the P- or C/A-codes to perform measurements. This type of receiver does not record any ephemeris data. Therefore, before a baseline solution is computed, an ephemeris file must be obtained from another source.

Code Receiver
An instrument that requires a knowledge of the P- or C/A-code to complete its measurements. This type of receiver will also record the broadcast ephemeris.

Collimate
To physically align a survey target or antenna over a mark.

Complete Instantaneous Phase Measurement
A measurement of carrier beat phase which includes the integer number of cycles of phase since the initial measurement. See *Fractional Instantaneous Phase Measurement; Integer-cycle Ambiguity.*

Control Points
A point to which coordinates have been assigned. These coordinates can then be held fixed and are used in other dependent surveys.

Control Segment
A worldwide network of GPS monitoring and control stations that ensure the accuracy of the GPS satellite orbits and operations of their atomic clocks. The original control segment consists of control facilities in Diego Garcia, Ascension Island, Kwajalein, and Hawaii, with a master control station at the Consolidated Space Operations Center (CSPOC) at Colorado Springs, Colorado.

Correlation Type Channel
A channel which uses a correlator to maintain alignment between a receiver generated code and/or carrier frequency and the incoming satellite code and/or carrier frequency.

Cycle Ambiguity
See **Ambiguity**.

Cycle Slip
A discontinuity in measured carrier beat phase resulting from a temporary loss of lock in the carrier tracking loop of a GPS receiver.

Datum
A horizontal or vertical reference system for making survey measurements and computations. Horizontal datums are typically referred to ellipsoids, the State Plane Coordinate System, or the Universal Transverse Mercator Grid System. Vertical datums are typically referred to the geoid. The vertical datum used in the United States is the National Geodetic Vertical Datum of 1929 (NGVD 29), formerly referred to as the Sea Level Datum of 1929. This datum will soon be upgraded to the North American Vertical Datum of 1988 (NAVD 88).

D-code (Data Message)
A 1,500-bit message included in the GPS signal which reports the satellite's location, clock corrections, and health. Included is rough information on the other satellites in the constellation.

Deflection of the Vertical
The angle between the perpendicular to the geoid (plumb line) and the perpendicular to an ellipsoid.

Delay Lock
A code correlation technique where the code received from a satellite is compared with "early" and "late" versions of the reference code generated by the receiver to obtain a bi-polar discrimination function.

Delta Pseudo-range
See *Reconstructed Carrier Phase.*

Differencing
A technique used in baseline processing to resolve the integer cycle ambiguity and to reduce a number of error sources including oscillator variations and atmospheric and orbital modeling errors. This technique "differences" the measurement of the carrier beat phase across time, frequency, receivers, satellites, or any combination of these. The most popular differences are described below:

A **single difference** between receivers is the instantaneous difference in the complete carrier beat phase measurements made at two receivers simultaneously observing the same signal.

A **double difference** between receivers and between satellites is found by differencing the single difference for one satellite with the single difference for another satellite where both single differences are from the same epoch.

A **triple difference** between receivers, between satellites, and between epochs (time) is the difference between a double difference at one epoch and the same double difference at the following epoch.

Differential Positioning
The determination of the position of an object station relative to a reference station when receivers at each station are simultaneously tracking the same signals.

Dilution of Precision (DOP)
A measure of the geometric contribution to the uncertainty of a position fix. The more popular terms are given below:

GDOP - Geometric Dilution of Precision - measurement accuracy in 3D position and time.

PDOP - Position Dilution of Precision (PDOP) - measurement accuracy in 3D position.

HDOP - Horizontal Dilution of Precision (HDOP) - measurement accuracy in 2D horizontal position.

VDOP - Vertical Dilution of Precision (VDOP) - measurement accuracy as standard deviation of vertical height.

RDOP - Relative Dilution of Precision (RDOP) - measurement of the quality of baseline reductions.

Doppler-aiding
Signal processing strategy that uses a measured Doppler shift to help the receiver smoothly track the GPS signal, allowing more precise velocity and position measurement.

Doppler Shift
The apparent change in frequency of a received signal due to the rate of change of the distance between the transmitter and receiver.

DSARC
Defense System Acquisition Review Council, the DoD body which must authorize any major defense system acquisition.

Dynamic Positioning
Determination of the position of a moving receiver such as one mounted in a boat. Generally, each set of coordinates are computed from a single data sample. The GPS was originally conceived for dynamic positioning of a single receiver; however, it may be used in a differential mode to increase relative accuracy. Also, referred to as **kinematic positioning**.

Eccentricity
The ratio of the distance from the center of an ellipse to its focus on the semimajor axis.

Elevation
The height of an object above some reference datum.

Ellipsoid
A geometric shape formed by revolving an ellipse about its minor axis. The term is used interchangeably with spheroid. An ellipsoid is defined by the length of its semimajor axis a and its flattening f, where:

$$f = (a - b)/a$$

and b = length of the semiminor axis.

The most commonly used ellipsoids in North America are:

Clarke 1866
Geodetic Reference System of 1980 (GRS 80)
World Geodetic System of 1972 (WGS 72)
World Geodetic System of 1984 (WGS 84)

Prior to January 1987, the GPS operated with reference to WGS 72. Since January 1987, it has been referenced to WGS 84. For most purposes, the GRS 80 and WGS 84 can be considered identical.

Ellipsoid Height
The elevation h of a point above or below the ellipsoid.

Ephemeris
A tabular statement of the positions of a celestial body (satellite) at regular intervals.

Epoch
A period of time or a date selected as a point of reference.

Fast Switching Channel
A switching channel with a time sequence short enough to recover the integer part of the carrier beat phase. The switching time is generally between 2 to 5 ms.

Flattening
See **Ellipsoid**.

Fractional Instantaneous Phase Measurement
A measurement of the carrier beat phase that does not include any integer cycle count.

Frequency Band
A range of frequencies in a region of the electromagnetic spectrum.

Frequency Spectrum
The distribution of signal amplitudes as a function of frequency of the constituent signal waves.

Fundamental Frequency
The GPS fundamental frequency F is 10.23 MHz. The carrier frequencies are:

L1 = 154 * F = 1575.42 MHz
L2 = 120 * F = 1227.60 MHz

Geoid
An equipotential surface approximating the earth's surface and corresponding with mean sea level in the oceans and its extension through the continents. In other words, the geoid would coincide with the surface to which the oceans would conform over the entire earth if the oceans were set free to adjust to the combined effect of the

earth's mass attraction and the centrifugal force of the earth's rotation.

Geodetic Leveling Network
A network of vertical control or benchmarks whose heights are known as accurately as possible, and whose horizontal positions are known only approximately.

Geoid Height
The elevation *N* of the geoid above or below the reference ellipsoid.

GPS
Global Positioning System. The GPS consists of the NAVSTAR satellites in six different orbits, five monitor stations, and the user community.

GPS Time
The broadcast GPS time signals are synchronized with atomic clocks at the GPS Master Control Station. These clocks are in turn periodically synchronized with Coordinated Universal Time (UTC). However, UTC is incremented by "leap seconds" to correct for the slowing of the earth's rotation with respect to the sun; GPS time is not. As of July 1990:

GPS time = UTC + 4 seconds

The fundamental time scale for all the earth's timekeeping is International Atomic Time (TAI). It is a continuous time scale not corrected by "leap seconds." There is a constant offset of 10 sec between GPS time and TAI such that:

GPS time = TAI - 10 sec

Handover Word
The word in the GPS message that contains time synchronization information for the transfer from the C/A-code to the P-code.

Horizontal Geodetic Network
A network for which the horizontal coordinate, latitude, and longitude of the control points in the network are determined as accurately as possible, and heights are known only approximately.

Independent Baseline
Those baselines that provide a unique position solution for a given station.

INS
Inertial Navigation System, which contains an Inertial Measurement Unit (IMU).

Integer-cycle Ambiguity
The unknown integer number of whole carrier cycles between the satellite and receiver.

Integrated Doppler
The accumulation of measured Doppler frequency multiplied by the time interval of measurement, so as to approximate the integral over time of the Doppler frequency.

Interferometry
See **Differential Positioning**.

Ionosphere
Region of the earth's atmosphere between the stratosphere and the exosphere approximately 50 to 250 miles above the surface of the earth.

Ionospheric Refraction Delay
A delay in the propagation of the GPS signal caused by the signal traveling through the ionosphere.

IRON
Inter Range Operation Number. A random number assigned to various orbiting objects assigned by the joint US/Canadian North American Air Defense Command (NORAD). Each of the GPS satellites has an individual IRON.

JPO
GPS Joint Program Office, originally located at the U.S. Air Force Space Division at El Segundo, California. The JPO consists of the US Air Force Program Manager and Deputy Program Managers representing the Army, Navy, Marine Corps, Coast Guard, Defense Mapping Agency, and NATO.

Kinematic Positioning
Often used to describe **dynamic positioning**. A GPS differential surveying technique, whereby one GPS unit, the fixed receiver, stays fixed on a known control point, while another GPS unit, the rover, collects data on a constantly moving vehicle, all the time continually tracking four or more satellites during the observation period. This process is done in an effort to ascertain the location or position of the rover receiver.

L-band
The radio frequency band from 390 MHz to 1550 MHz. The primary L-band signal radiated by each NAVSTAR satellite is L1 at 1575.42 MHz. The L1 beacon is modulated with the C/A- and P-codes, and with the NAV message. L2 is centered at 1227.50 MHz.

L1
See **L-band**.

L2
See **L-band**.

Lock
The state of noninterruption in the reception of a radio signal.

Monitor Station
One of five worldwide stations maintained by the DoD and used in the GPS control segment to monitor and control satellite clock and orbital parameters. Corrections are calculated and uploaded to each satellite at least once per day. See **Control Segment**.

Multichannel Receiver
A receiver containing multiple channels.

Multipath
A phenomenon similar to "ghosts" on a television screen whereby GPS signals from a satellite arrive at an antenna having traversed different paths. The signal traversing the longer path may have been reflected off one or more objects--the ground, a vehicle, boat, building or some other surface--and once received by the antenna, will yield a larger pseudo-range estimate and increase the error. Multipath usually results in **multipath error**.

Multipath Error
A positioning error resulting from radio signals travelling from the transmitter to the receiver by two paths of different electrical lengths.

Multiplexing Channel
A receiver channel that is sequenced through a number of satellite signals, each from a specific satellite.

NAV Data
The 1,500-bit NAVigation message broadcast by each satellite at 50 bps on both L1 and L2 beacons. This message contains system time, clock correction parameters, ionospheric delay model parameters, and the vehicle's ephemeris and health. This information is used to process GPS signals to obtain user position and velocity. Sometimes referred to as the **Navigation message**.

Navigation Message
See **NAV data**.

NAVSTAR
NAVigation Satellite Timing and Ranging. NAVSTAR is the name give to GPS satellites, originally manufactured by Rockwell International.

Observing Session
The period of time over which data are collected.

Orthometric Height
The elevation H of a point above or below the geoid. A relationship between ellipsoid heights and orthometric heights is obtained from the following equation:

$$h = H + N$$

where

h = ellipsoidal height

H = orthometric height

N = geoidal height

Outage
The period of time when a Dilution of Precision exceeds a specified maximum.

Perigee
The point in the orbit of a satellite about the earth that is the least distant from the center of the earth.

Phase Lock
The technique where the phase of a signal is set to replicate the phase of a reference signal by comparing the phase of the two signals and then using the resultant phase difference to adjust the reference oscillator to eliminate the difference.

Phase Measurement
A measurement, expressed as a percentage of a portion of a wave (e.g., a sine wave). For example, a complete wavelength is 100 percent; one-half is 50 percent; etc.

Phase Observable
See **Reconstructed Carrier Phase**.

Polar Plot
A circular plot in which elevation and azimuth as a function of time for each satellite, with respect to a specified location, are predicted and plotted.

Positioning
Determination of a position (usually a GPS antenna) with respect to a coordinate system (WGS 84, UTM, State Plane, etc.).

Precise Ephemeris
The ephemeris computed after the transmission of the satellite signal and based on satellite tracking information.

Precise or Protected Code (P-Code)
A sequence of pseudo-random binary biphase modulations on the GPS carrier at a chip rate of 10.23 MHz which repeats once every 267 days. Each 1-week segment of code is unique to a particular GPS satellite and is generally reset each week.

Precise Positioning Service (PPS)
Dynamic positioning of a single receiver based on the P-code. Currently, the PPS is the most accurate dynamic positioning service offered with GPS.

Pseudolite
A ground-based GPS station that can be used in a ranging solution. The station transmits a signal with a structure similar to that of an actual GPS satellite.

Pseudo-random Noise (PRN)
When used as a description of code, it indicates that the code has some random noise-like properties. Each GPS satellite has a unique PRN number assigned to it.

Pseudo-range
The time shift required to align a replica of the GPS code generated in the receiver with the code received from the satellite, scaled into distance by the speed of light. The time shift is the difference between the time of signal of reception and the time of signal transmission where the reception is measured in the receiver time reference and the transmission is measured in the satellite time reference. Therefore, the pseudo-range contains several errors including satellite/receiver time offset, and satellite ephemeris error.

Pseudo-range Difference
See **Reconstructed Carrier Phase**.

Pseudo-range Observable
The difference between the time of transmission and the time of arrival of a particular signal transmitted by the satellite.

Reconstructed Carrier Phase
The difference between the incoming Doppler-shifted carrier phase and the phase of a nominally constant reference frequency generated in the receiver. In dynamic applications, the reconstructed carrier phase is sampled at epochs of the received message code, and the difference in reconstructed carrier phase between consecutive code epochs is a measure of the change in satellite-to-receiver range between epochs. This is referred to as the pseudo-range difference, or the delta pseudo-range. In static positioning, the reconstructed carrier phase is sampled at epochs determined by the receiver clock. The reconstructed carrier phase changes according to the continuously integrated Doppler shift of the incoming signal, biased by the integral of the frequency offset between the satellite and receiver oscillators. The reconstructed carrier phase can be referred to the range between satellite and receiver once the phase ambiguity has been resolved. One cycle change in the reconstructed carrier phase is one wavelength of the carrier signal change in the range from satellite to receiver.

Relative Positioning
See **Differential Positioning**.

Satellite Constellation
The arrangement of a set of satellites in space.

Satellite Message
Sometimes, referred to as the Data (D) code. A low-frequency (50 Hz) stream of data on both carriers (L1 and L2) of the satellite signal. The stream of data is designed to inform the user about the health and position of the satellite. The satellite message can be decoded by the receiver and used for positioning in real time.

S-Code
Another name for the C/A-Code.

Selective Availability (S/A)
The policy of the DoD to intentionally degrade the accuracy obtainable from GPS by civilian users.

Simultaneous Measurements
A measurement or set of measurements referred to the same epoch.

Slow Switching Channel
A channel that switches with a period too long to recover the integer part of the carrier phase.

Space Segment
The portion of the GPS system with major components in space (e.g., GPS satellites).

Spheroid
Used interchangeably with **ellipsoid**.

Squaring-type channel
A receiver channel that multiplies the received signal by itself to obtain a second harmonic of the carrier which does not contain the code modulation.

Standard Positioning Service (SPS)
Positioning of a single receiver based on the C/A-Code. Also see **PPS**.

Static Positioning
Determination of the position of a stationary receiver.

Stop-and-Go Kinematic Surveying
A GPS differential survey technique whereby one GPS unit, the fixed receiver, remains fixed on a known control point, while the other, a rover receiver, collects signals on a point of unknown position for a short period of time, usually minutes, and then moves to subsequent points to collect signals for a few more minutes, all the time continually tracking four or more satellites during the observation period. This process is done in an effort to ascertain the position of the object stations occupied by the rover receiver.

Switching Channel
A channel that is sequenced through a number of satellite signals at a rate that is slower than and asynchronous with the message data rate.

Time Tag
The time appended to an actual measurement.

Translocation
See **Differential Positioning**.

Troposphere
Inner layer of the atmosphere, located between 6 and 12 miles above the earth's surface.

User Equivalent Range Error (UERE)
A term for GPS measurement accuracy which represents the combined effects of ephemeris uncertainties, propagation errors, clock and timing errors, and receiver noise. A high UERE may indicate that S/A has been imposed on the satellite used.

User Segment
The portion of the GPS with major components that can be directly interfaced by the user (e.g., GPS receivers).

Visibility Plot
A plot against time of day of the number of satellites which are visible from a specified location.

Y-code
The P-code after encryption.

Z-count Word
The GPS satellite clock time at the leading edge of the data subframe of the transmitted GPS message.

Appendix C
Sources of GPS Information

Listed below are other sources of GPS information:

a. Civil GPS Service GPS Information Center. The GPS Information Center (GPSIC) of the U.S. Coast Guard operates under the Civil GPS service Steering Committee. The GPSIC will receive GPS status messages from the U.S. Air Force's 2nd Satellite Control Squadron (2SCS), located in Colorado Springs, and disseminate the information via a bulletin board. Current services include current constellation status, future schedule outages, and an almanac suitable for making GPS coverage and satellite visibility predictions. This bulletin board, a voice recording, and live information is accessible 24 hr a day, 7 days a week.

GPSIC voice recording	(703) 313-5907
GPSIC live information	(703) 313-5900

For Bulletin Board Information:

Comm. Parameters: 8 data bits, 1 stop bit, no parity
Modem access # (703) 313-5910

b. GPS satellite clock behavior and related information. Information on satellite clock behavior and related GPS information can be obtained from:

U.S. Naval Observatory
Washington, DC 20392-5100

Telephone Lines:	(202) 653-0068, 0155, 1079
Baud Rates:	1200, 2400, or 9600
Comm. parameters:	8 data bits, 1 stop bit, no parity terminate lines with CR/LF]
Internet access:	Telnet to tycho.usno.navy.mil (192.5.41.239) Log in as ads
Comments to:	adsmgr@tycho.navy.mil

USNO Series 4 Weekly Bulletins: Received by mail, they contain information on the status of GPS including GPS time steering and satellite clock behavior.

For operational comments, contact the Time Service Department of the National Observatory at (202) 653-1525 for further assistance.

c. General GPS bulletin boards. There are several bulletin board services (BBS) that list general GPS information.

(1) Holloman AFB. Provides daily almanac, observed range errors, comments on the satellites, and the OCS Advisories. Requires fill duplex, 8 data bits, 1 stop bit, no parity, or full duplex, 7 data bits, 1 stop bit, odd or even parity.

300 to 2400 baud:	(505) 679-1525
Live system operator:	(505) 679-1657

(2) Free hourly almanac:

Global Satellite Software, Inc.
5339 Prospect Road, Suite 239
San Jose, CA 95129
Telephone: (408) 252-7358
Baud Rate: 300 to 9,600
Contact: (408) 252-7490 for further information.

(3) Post-broadcast ephemeris data:

Associated Consulting Inc.
2245 N. Decatur Blvd.
Las Vegas, NV 89108
Telephone: (702) 647-9266
Baud: 300 to 14,400
System operator: (702) 647-9265

d. Precise GPS orbit information. There are various agencies or firms that provide GPS orbit information:

(1) Government. Precise orbital positions and velocities based on post-computations of tracking data are available from NGS. Satellite orbital data are scheduled to be available two weeks after the tracking data are collected. For further descriptions on formats, fee schedule, or to order data, contact:

NOAA, National Geodetic Survey, N/CG174
1315 East-West Highway
Silver Spring, MD 20910-3282
Telephone: (301) 713-3242
Fax: (301) 713-4172

(2) Commercial. Precise orbit data are available from the Aero Service Division, Western Atlas International, using data obtained from its tracking network

stations. For description of format, fee schedule, or to order data, contact:

Western Geophysical Division
A Division of Western Atlas Int'l
3600 Briarpark Drive
Houston, TX 77042-4299
Telephone: (713) 964-6345
Fax: (713) 964-6555

e. Performance evaluation of GPS survey equipment. For information on equipment tested or to comment on the GPS satellite survey system, contact:

GPS Test Coordinator
National Geodetic Survey Division, N/CG14
1315 East-West Highway
Silver Spring, MD 20910-3282
Telephone: (301) 713-3242
Fax: (301) 713-4172

f. General Information on GPS for USACE Personnel can be obtained from:

U.S. Army Topo Engrg Center
ATTN: CETEC-TD-AG
7701 Telegraph Road
Alexandria, VA 22315-3864

Phone: (703) 428-6766
Fax: (703) 428-8176

Appendix D
Static GPS Survey Examples

Section I
Survey No. 1: HORIZONTAL CONTROL GPS SURVEY (Ukiah Airport, California)

D-1. Planning Phase

The GPS survey was planned for 25 April 1989 in the vicinity of Ukiah Airport, Ukiah, California.

a. A diagram of the project area is shown in Figure D-1.

b. Four SPS (C/A-code) GPS carrier phase tracking receivers were used for the survey, one person per receiver. In actuality, because the personnel were inexperienced in conducting a GPS survey, a fifth person was also used. The fifth person was used as a "runner" who can be called upon during the survey to aid in smoothing out any complications (e.g., aiding in overall communication and coordination, parts retrieval in case of breakdown, bad power source, blown fuse, misplaced equipment, forgotten measurement device or power cord, as well as any other possible complication). Communication between personnel was by two-way radio. Care was taken in choosing and operating the two-way radio near the GPS survey so that the radio transmitter and receiver chosen, when in operation, would not interfere with the GPS receiver.

c. Prior to data collection, the stations were inspected and found to be acceptable (easy accessibility, no obstruction or possible multipath sources, and at least 20° satellite visibility above the horizon).

d. The date 25 April 1989 corresponds to Julian calendar day 115. Calpella, Perry, and Ukiah Airport were stations with established horizontal control. Pier 1 and Pier 2 were stations requiring horizontal coordinates accurate to 1:10,000 (refer to Figure D-2). Therefore, the following station conventions for Session 1 of the survey were:

Pier 1 - Station 20011151
Pier 2 - Station 20021151
Calpella - Station 20131151
Ukiah Airport - Station 20141151

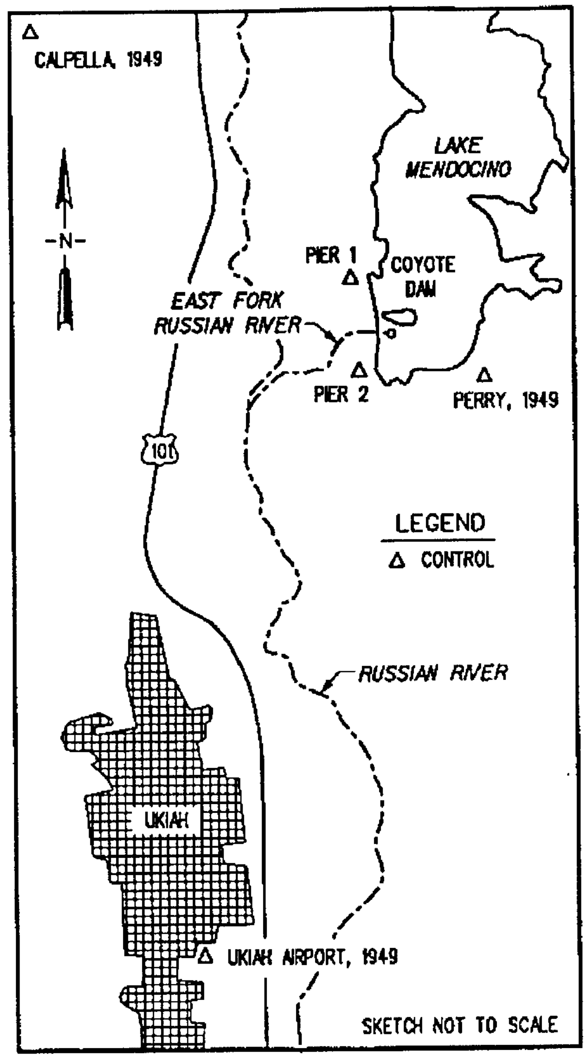

Figure D-1. Ukiah project area

It is important to note that this station convention was used for this survey because the receiver used only allowed numeric input of station names. Most newer receivers allow alphanumeric inputs for station names which provides more flexibility in station naming. (Consult the GPS manufacturer literature for further explanation and guidance on the receiver's station naming convention.)

e. A satellite visibility plan (a software package that produces a hard copy listing of satellite constellations and

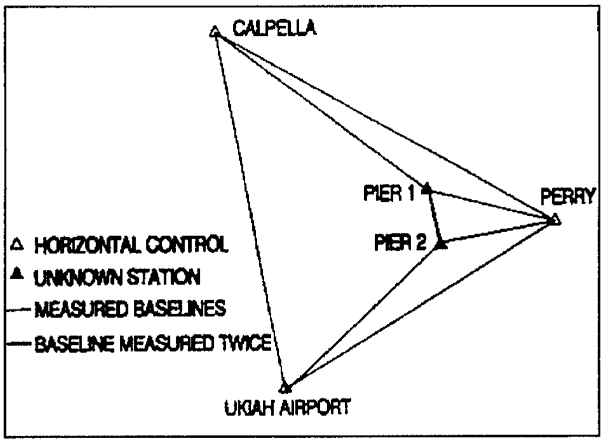

Figure D-2. GPS project diagram (Ukiah)

time availability based on ephemerides) was run for the project location. The satellite visibility was run with the most up-to-date ephemeris for the period of observation, using four-satellite visibility, and with a cutoff elevation angle of 20°. An up-to-date ephemeris was used to ensure the satellite visibility formulated was the most accurate. Four-satellite visibility was run in order to formulate accurate 3D solutions. A cutoff elevation of 20° was chosen in order to minimize any diffusion or dispersion of the signal by the atmosphere which in turn may cause errors in the solution as the satellites pass near the horizon. The satellite visibility plan produced for the Ukiah project is shown below.

<u>All-In-View PDOP for Ukiah</u>

Date: 25 Feb 1990 — Latitude: 39° 12' 30" N
Time: 4:00 -> 4:00 — Longitude: 123° 10' 30" W
Cutoff Elevation: 20 — Zone: - 7:00

Satellite Constellation	Time Rise	Time Set	dT	PDOP Rise	PDOP Set
6 9 11 13	21:55	22:03	0:08	4.9	5.0
6 9 11 12 13	22:02	22:33	0:30	3.8	3.6
6 9 11 12 13 19	22:32	23:18	0:45	3.2	3.3
3 6 9 11 12 13 19	23:17	23:48	0:30	2.9	3.0
3 9 11 12 13 19	23:47	1:08	1:20	4.2	4.2
3 11 12 13 19	1:07	1:22	0:15	4.9	5.0
3 12 13 19	1:22	2:20	0:58	22.7	31.6

The portion of the satellite visibility where the PDOP is near 5.0 m/m or below are times when the satellite geometry is conducive for conduct of a survey. A PDOP near or below 5.0 m/m does not guarantee a successful survey but it does indicate good satellite geometry during that moment of the survey (see Chapter 5 for further information on PDOP).

f. From the satellite visibility plan, it was decided to conduct three sessions during the survey. Travel between survey sites, time to set up and take down the equipment before and after the survey, receiver warm-up time, time of survey (at least an hour allotment for survey data collection, but more than an hour if at all possible), and possible time loss due to unforeseeable problems or complications were taken into account before deciding on a specific session schedule. The final survey session schedule is shown in Table D-2.

Table D-2
Final Survey Session Schedule

Session	Start Time	Stop Time
1	21:55	22:55
2	23:38	00:38
3	01:23	02:20

It was further decided which stations would be occupied during each session. Station occupation was designed to minimize travel time and to add to the overall efficiency of the survey. The station occupation schedule was planned as shown in Table D-3.

Table D-3
Station Occupation Schedule

Session	Station	Station	Station	Station
1	Calpella	Ukiah Airport	Pier 1	Pier 2
2	Calpella	Perry	Pier 1	Pier 2
3	Ukiah Airport	Perry	Pier 1	Pier 2

g. A GPS station observation log is generally filled out prior to conduct of the survey. An example of a GPS log is shown in Figure D-3. The log must be filled out for each of the stations occupied in order to have a written record of the actual survey and as an aid for the personnel occupying each of the stations.

h. Portions of the GPS station observation log were filled out prior to data collection. These portions included the station name, start date, GPS 8-character ID for each session, project name, project location, observer name, approximate receiver position (latitude, longitude, and elevation), session scheduled start and stop times, and requisite tracking equipment information. In this case, six GPS station observation logs were filled out, one each

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****

PROJECT NAME ____________________ LOCALITY ____________
OBSERVER ________________ AGENCY/FIRM ________________
RECEIVER ________________________ S/N ________________
ANTENNA _________________________ S/N ________________
DATA RECORDING UNIT _____________ S/N ________________
TRIBRACH ____________ S/N ______ LAST CALIBRATED: ______

****

	SESSION 1		SESSION 2		SESSION 3	
STATION: NAME	________		________		________	
NUMBER	________		________		________	
DAY OF YEAR	________		________		________	
DATE MM DD YY	________		________		________	
UTC TIME OF OBSERVATION	START	STOP	START	STOP	START	STOP

****

ANTENNA HEIGHT MEASUREMENTS

	SESSION 1	SESSION 2	SESSION 3
SLOPE @ BEGINNING	___ IN= ___ M	___ IN= ___ M	___ IN= ___ M
	MN = ___ M	MN = ___ M	MN = ___ M
SLOPE @ END	___ IN= ___ M	___ IN= ___ M	___ IN= ___ M
	MN = ___ M	MN = ___ M	MN = ___ M
MN ADJ TO VERT:	___ M	___ M	___ M

****

	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION
LAT	____	____	____	____	____	____
LONG	____	____	____	____	____	____
HT	____	____	____	____	____	____
PDOP	____	____	____	____	____	____
SVS TO TRACK	________		________		________	
LOCAL TIME:	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL
START	____	____	____	____	____	____
STOP	____	____	____	____	____	____

****

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a. Front

Figure D-3. Example GPS station observation log (front and back) (Continued)

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****

	SESSION 1	SESSION 2	SESSION 3
ANT CABLE LENGTH	______	______	______
POWER SUPPLY	______	______	______
WEATHER CONDITIONS	______	______	______
MONUMENT TYPE	______	______	______
EXACT STAMPING	______	______	______
AGENCY CAST IN DISK	______	______	______

****

SKETCH OF SITE

SESSION 1	SESSSION 2	SESSION 3

****

Describe any abnormalities and/or problems encountered during the survey, include session number, time of occurence and duration.

****

PAGE 2

b. Back

Figure D-3. (Concluded)

for: Calpella (Sessions 1 and 2), Ukiah Airport (Session 3), Ukiah Airport (Session 1), Perry (Sessions 1 and 2), Pier 1 (Sessions 1, 2, and 3), and Pier 2 (Sessions 1, 2, and 3). An example of a GPS station observation log for Pier 2 is shown in Figure D-4.

D-2. Actual Survey Operation

These portions of the GPS station observation log which were not filled out during the planning phase of the survey were filled out during data collection. An example of the GPS station observation log for Pier 2, filled out after data collection, is shown in Figure D-5.

a. The key to proper data collection is the correct setup of the equipment (tripod, receiver, and power source) and correct antenna height measurements (height of the antenna above the mark).

b. Figure D-6 shows personnel correctly taking an antenna height measurement over a temporary monument. Figure D-7 illustrates a typical antenna setup with the following equation detailing the antenna height correction.

$$v = \sqrt{(s)^2 - (r)^2} \tag{D-1}$$

where

v = corrected vertical height distance of the antenna center above the mark

s = slope distance measurement derived from the average of several antenna height measurements made

r = antenna radius

c. When measuring the antenna height during this survey, the procedure below was followed in order to ensure an accurate reading:

(1) The slope distance from the north point of the antenna to the center of the monument was measured to the nearest millimeter (0.001 m). Measurement was also done in non-SI units (inches) to the nearest 1/32 of an inch. This value then was compared to the metric value measured earlier in order to detect blunders.

(2) Similar measurements were also taken from the south point of the antenna to the center of the monument.

(3) The resultant north and south slope distances were averaged.

(4) *Example*: (Refer to Figure D-5.)

(a) Tripod set up flat on a dock.

(b) The north side measure up for session 1 = 0.120 m.

(c) The south side measure up for session 1 = 0.120 m.

(d) An extra "Check Measurement" was also taken for the measure up for Session 1 and was found to be 0.394 ft.

(e) As a check: (0.394 ft.) x (1 m/3.281 ft.) = 0.120 m.

(f) This value was recorded in the GPS station observation log.

d. Each GPS receiver was operated in direct accordance with the manufacturer's instructions, procedures, and/or guidance.

e. No problems were encountered during the survey sessions.

D-3. Post-Processing Observation Data

All observation data recorded were downloaded from the receivers to a 5.25-in. floppy disc. The downloading procedures detailed in the manufacturer's operating manuals were strictly adhered to.

a. Once the observation data were downloaded, preprocessing of data was performed. Preprocessing of data included checking the station names, antenna heights, latitude, longitude, and elevation of the points, as well as applying any required corrections. In general, most GPS processing software requires the antenna slope height be corrected to vertical at some point in the survey, usually during the pre-processing phase. (Consult receiver/software manufacturer guidelines for specifics.)

b. The data for the Ukiah project were post-processed using TRIMBLE software, but in general, all post-processing software produces similar results. The

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PROJECT NAME COYOTE DAM LOCALITY UKIAH, CA
OBSERVER LARRY LAMB AGENCY/FIRM COE, SACRAMENTO DISTRICT
RECEIVER TRIMBLE 4000 SL S/N 2820A00223
ANTENNA TRIMBLE MICRO SL S/N 2816A00224
DATA RECORDING UNIT RECEIVER S/N 2820A00224
TRIBRACH WILD GDF 22 S/N N/A LAST CALIBRATED: 4/24/89

	SESSION 1		SESSION 2		SESSION 3	
STATION: NAME	PIER 2		PIER 2		PIER 2	
NUMBER	2002		2002		2002	
DAY OF YEAR	115		115		115	
DATE MM DD YY	4/25/89		4/25/89		4/25/89	
UTC TIME OF OBSERVATION	START 04:56	STOP 05:55	START 06:10	STOP 07:38	START 07:55	STOP 09:20

ANTENNA HEIGHT MEASUREMENTS

	SESSION 1	SESSION 2	SESSION 3
SLOPE @ BEGINNING	___ IN= ___ M	___ IN= ___ M	___ IN= ___ M
	MN = ___ M	MN = ___ M	MN = ___ M
SLOPE @ END	___ IN= ___ M	___ IN= ___ M	___ IN= ___ M
	MN = ___ M	MN = ___ M	MN = ___ M
MN ADJ TO VERT:	___ M	___ M	___ M

	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION
LAT	39-12-30		39-12-30		39-12-30	
LONG	123-10-30		123-10-30		123-10-30	
HT	244.0		244.0		244.0	
PDOP	3.6		4.8		4.0	
SVS TO TRACK	02,03,06,09 11,12,13,14		02,03,06,09 11,12,13,14		03,06,09,11 12,13,14,16	

LOCAL TIME:	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL
START	21:55		23:38		01:20	
STOP	22:55		00:38		02:20	

PAGE 1

a. Front

Figure D-4. GPS station observation log, presurvey (Continued)

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****

	SESSION 2	SESSION 2	SESSION 3
ANT CABLE LENGTH	100 ft	100 ft	35 ft
POWER SUPPLY	12 v DC	12 v DC	12 v DC
WEATHER CONDITIONS			
MONUMENT TYPE	"C" (SET IN PIER)	← SAME	← SAME
EXACT STAMPING	PIER 2 1953	← "	← "
AGENCY CAST IN DISK	COE	← "	← "

****

SKETCH OF SITE

SESSION 1	SESSION 2	SESSION 3

****

Describe any abnormalities and/or problems encountered during the survey, include session number, time of occurence and duration.

****

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b. Back

Figure D-4. (Concluded)

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****

PROJECT NAME COYOTE DAM LOCALITY UKIAH, CA
OBSERVER LARRY LAMB AGENCY/FIRM COE SACRAMENTO DISTRICT
RECEIVER TRIMBLE 4000SL S/N 2820A00223
ANTENNA TRIMBLE [illegible] SL S/N 2816A00224
DATA RECORDING UNIT RECEIVER S/N 2820A00224
TRIBRACH WILD GDF 22 S/N N/A LAST CALIBRATED: 4/24/89

****

	SESSION 1		SESSION 2		SESSION 3	
STATION: NAME	PIER 2		PIER 2		PIER 2	
NUMBER	2002		2002		2002	
DAY OF YEAR	115		115		115	
DATE MM DD YY	4/25/89		4/25/89		4/25/89	
UTC TIME OF OBSERVATION	START	STOP	START	STOP	START	STOP
	04:56	05:55	06:10	07:38	07:55	09:20

****

ANTENNA HEIGHT MEASUREMENTS

	SESSION 1	SESSION 2	SESSION 3
SLOPE @ BEGINNING	0.120 0.120 0.120	0.116 0.116 0.116	0.123 0.124 0.124
	4 12/16 IN= 0.121 M	4 9/16 IN= 0.116 M	4 14/16 IN= 0.124 M
	MN = 0.120 M	MN = 0.116 M	MN = 0.1238 M
SLOPE @ END	4 12/16 4 12/16 4 11/16	4 9/16 4 9/16 4 9/16	4 13/16 4 14/16 4 14/16
	0.120 IN= 4 12/16 M	0.116 IN= 4 9/16 M	0.123 IN= 4 13/16 M
	MN = 0.120 M	MN = 0.116 M	MN = 0.1230 M
MN ADJ TO VERT:	0.120 M	0.116 M	0.1234 M

****

	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION
LAT	39-12-30	39-12-22.64	39-12-30	39-12-22.48	39-12-30	39-12-22.81
LONG	123-10-30	123-10-33.42	123-10-30	123-10-33.20	123-10-30	123-10-33.62
HT	244.0	210.6	244.0	199.8	244.0	222.8
PDOP	3.6	–	4.8	–	4.0	–
SVS TO TRACK	02,03,06,09 11,12,13,14		02,03,06,09 11,12,13,14		03,06,09,11 12,13,14,16	
LOCAL TIME:	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL
START	21:55	21:56	23:38	23:10	01:20	00:55
STOP	22:55	22:55	20:38	00:38	02:20	02:20

****

PAGE 1

a. Front

Figure D-5. GPS station observation log, postsurvey (Continued)

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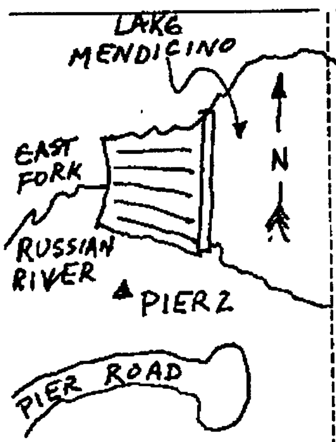
****

	SESSION 1	SESSION 2	SESSION 3
ANT CABLE LENGTH	100 Ft	100 Ft	35 Ft
POWER SUPPLY	12 V DC	12 V DC	12 V DC
WEATHER CONDITIONS	CLEAR, COOL 45°	CLEAR, COOL 40°	CLEAR, COOL 40°
MONUMENT TYPE	"C" (SET IN PIER)	← SAME	← SAME
EXACT STAMPING	PIER 2 1953	← "	← "
AGENCY CAST IN DISK	COE	← "	← "

****

SKETCH OF SITE

SESSION 1	SESSION 2	SESSION 3
	← SAME	← SAME

****

Describe any abnormalities and/or problems encountered during the survey, include session number, time of occurance and duration.

THE ANTENNA WAS MOUNTED DIRECTLY OVER PIER 2 WITH NO TRIPOD USED.
ANTENNA HEIGHT WAS MEASURED VERTICALLY FROM - GROUND PLANE TO BRASS DISK.

****

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Figure D-5. (Concluded)

Figure D-6. Antenna height measurement

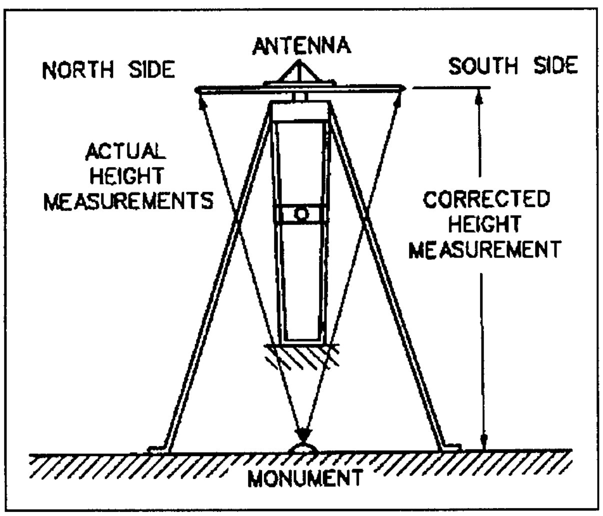


Figure D-7. Diagram of antenna setup

observation data were processed in accordance with manufacturer's guidelines. (See Chapter 10 for further discussion on post-processing.)

(1) An examination of the results reveals the following, which are produced in one form or another in other manufacturer's solution file formats:

(a) Listing of the file name.

(b) Types of solutions (single, double, or triple difference).

(c) Satellite availability during the survey for each station occupied.

(d) Ephemeris file used for solution formulation.

(e) Type of satellite selection (manual or automatic).

(f) Elevation mask.

(g) Minimum number of satellites used.

(h) Meteorological data (pressure, temperature, humidity).

(i) Session time (date, time).

(j) Data logging time (start, stop).

(k) Station information:

- Location (latitude, longitude)
- Receiver serial number used
- Antenna serial number used
- ID number
- Antenna height

(l) RMS.

(m) Solution files:

- Δx, Δy, Δz between stations
- Slope distance between stations
- Δlatitude, Δlongitude between stations
- Distance between stations
- Δheight

(n) Epoch intervals.

(o) Number of epochs.

(2) The triple difference, double difference float, and double difference fix TRIMBLE solutions of the baseline reductions for 2014->2002 are shown annotated with the above conventions (a - o) provided as an explanation.

c. In general, all GPS manufacturer data reduction software programs produce a summary of results once data have been reduced and a baseline formulated.

d. The listing of the baseline formulations for line 2014 to 2002 follows in Figure D-8, as reproduced from the TRIMBLE Navigation TRIMVEC solution file.

e. Although the TRIMBLE summary solution file does specify that the integers were found, the RMS is OK, and FIXED solution is recommended, an analysis of the output prior to this conclusion in accordance with Chapter 10 would have revealed the following:

(1) With a baseline distance of 7,000 m for the formulated baseline (baseline 1402) and from Table 10-1, the RMS must be less than [(0.02 + (0.004*d))]. Using the equation [(0.02 + (0.004/d))] from Table 10-1 with a d (distance) equal to 7 km, the equation is [(0.02 + (0.004*7))] and the RMS is approximately equal to 0.048. Therefore, the RMS is acceptable.

(2) With a baseline distance of 7,000 m for the formulated baseline (baseline 1,402) and from Table 10-1, the quality factor ratio must be more than 3. The fixed solution factor from the summary solution file is 18.9. Therefore, the fixed solution quality factor is acceptable.

(3) From Table 10-1, with a baseline length of 7 km for baseline 1402 (between 0 and 20 km), an acceptable RMS (small), an acceptable quality factor ratio (large), and an integer solution, the fixed solution should be acceptable.

f. All other formulated baselines for this survey were found to be acceptable.

D-4. Loop Closure

An approximate loop closure was done by following the procedures detailed in Chapter 10. The resulting calculations would proceed as shown in the following computation:

a. Follow Figure D-9, holding 2013 as the starting point.

b. Formulate a table similar to Table 10-3 (see page D-25), where all values are taken from the GPS post-processed baseline formulations:

c. Sum up the Δx, Δy, Δz, and distance components:

ΣΔx components = Δx(2013->2014) + Δx(2014->2002)
+ Δx(2002->2006) + Δx(2006->2001)
+ Δx(2001->2013)
= -3,367.429 + 3,799.005 + 953.294
+ (-666.617) + (-718.244)

= <u>0.009</u>

ΣΔy components = Δy(2013->2014) + Δy(2014->2002)
+ Δy(2002->2006) + Δy(2006->2001)
+ Δy(2001->2013)
= -7,891.019 + 2,554.018
+ (-748.319) + 1,441.548 + 4,643.775

= <u>0.003</u>

ΣΔz components = Δz(2013->2014) + Δz(2014->2002)
+ Δz(2002->2006) + Δz(2006->2001)
+ Δz(2001->2013)
= -10,410.673 + 5,296.798
+ (-16.709) + 908.280 + 4,222.288

= <u>-0.016</u>

ΣDistances = (2013->2014) + (2014->2002)
+ (2002-2006) + (2006->2001)
+ (2001->2013)
= 13,490.362 + 7,000.823 + 1,212.035
+ 1,829.593 + 6,317.297

= <u>29,850.110</u>

d. From Equation 10-1:

$$M = \sqrt{(0.009)^2 + (0.003)^2 + (-0.016)^2} \tag{D-2}$$

$$= \sqrt{(0.000081) + (0.000009) + (0.000256)} \tag{D-3}$$

= 0.018601075 or 0.0186

Therefore, misclosure is approximately 0.0186 in., 29,850.110 m, or 1 part in 1,600,000.

D-5. Final Adjustment

The program used for final adjustment of the Ukiah survey was the GEOLAB program. For an in-depth technical discussion on GEOLAB, refer to the literature accompanying the GEOLAB software package. The following discussion on the GEOLAB adjustment of the Ukiah survey highlights some of the criteria used in the adjustment of a horizontal survey.

TRIMBLE NAVIGATION, LTD.
585 NORTH MARY AVENUE
SUNNYVALE, CALIFORNIA 94086
U.S.A.

PROGRAM TRIMVEC
GPS RELATIVE POSITIONING SOLUTION
VERSION 88.028

```
File name: 14022059.trp                         a - listing of the filename
Coordinate system - WGS-84                      b - type of solution

Type solution:  Triple difference               i - session time

Start date/time: 1988/ 2/29  7:26:30  day of year 60  tow 113190.
Stop  date/time: 1988/ 2/29  9:32:30  day of year 60  tow 120750.

Data available                                  c - satellite availability

station:  1
sat: 6 :....................                                      :
sat: 8 :....                                                      :
sat: 9 :.........................................................:
sat:11 :...............................................           :
sat:12 :.........................................................:
sat:13 :.........................................................:
sat: 3 :                 ........................................:

station:  2
sat: 6 :........                                                  :
sat: 8 :....                                                      :
sat: 9 :..................................  .                     :
sat:11 :.............................................             :
sat:12 :.........................................................:
sat:13 :.........................................................:
sat: 3 :                    .....................................:

Ephemeris file used: 20140592.eph               d - ephemeris file used
```

SATELLITE	AODE(hr.)	HEALTH	WEEK NO.	TOW(sec)	URA(m)
6	3.41	0	425	113040.00	5.7
8	4.55	0	425	113040.00	999.0
9	7.96	0	425	112770.00	4.0
11	3.98	0	425	112770.00	2.8
12	6.26	0	425	112770.00	5.7
13	4.55	0	425	112770.00	16.0
3	7.40	0	425	114570.00	2.0

Broadcast satellite clock correction values   c - satellite availability

prn	af0	af1	af2	toc
6	-.8698371239D-03	-.1784883352D-10	-.2775557562D-16	.1188D+06
8	.4412536509D-03	-.7498783816D-09	-.2775557562D-16	.1188D+06
9	.2129529630D-03	.1354242053D-11	-.2775557562D-16	.1188D+06
11	-.9965850040D-04	-.4888534022D-11	.0000000000D+00	.1188D+06
12	.6357054226D-03	.5343281373D-11	.0000000000D+00	.1188D+06
13	.3238730133D-03	.2273736754D-11	.0000000000D+00	.1188D+06
3	.4011737183D-03	-.6821210263D-12	.0000000000D+00	.1188D+06

Figure D-8. TRIMBLE solution file (Ukiah) (Sheet 1 of 13)

```
Message file for station 1
..........................................................
Station ID: 2014  Session #: 059-2   Feb. 29, 1988 07:24
Reference Position - HIGH ACCURACY:
Lat.= 39:07'57.401"N  Long.=123:12'14.788"W Height=190.2 [meters]
Antenna height = 1.4387 [meters] (entered in the field in feet)
Receiver serial # = 4604
Antenna serial # = 110 (entered in the office)
                                              k - station information
Survey schedule mode     = AUTOMATIC
Data-logging start time = 07:26
Data-logging stop  time = 09:33   j - data logging time   c - satellite
                                                              availability
         Ch0    Ch1    Ch2    Ch3    Ch4    Ch5    Ch6    Ch7    Ch8    Ch9
SVs        3      6      8      9     11     12     13      0      0      0
# meas   379    170     28    506    445    506    506      0      0      0
# cont   379    170     28    506    445    506    506      0      0      0

SV Selection mode = MANUAL SELECTION        e - type of satellite
Elevation mask     = 20     [degrees]  Minimum # of SVs = 4  selection
                          F                  g - minimum # of satellites
4 SV Position      Best PDOP Position [ 3.1]    Mean Position [497]   used
Latitude:            39:07'57.17388" N            39:07'57.14899" N
Longitude:         123:12'14.47260" W           123:12'14.64029" W
Height [m]:                   169.0                        170.3

3 SV Position      Best PDOP Position [ 2.5]    Mean Position [9]
Latitude:            39:07'57.62620" N            39:07'57.51783" N
Longitude:         123:12'14.95426" N           123:12'14.88427" N
..........................................................
Origin of station 1 coordinates: Best C/A code tracking solution
   STATION (mark) 1
                                              k - station information
input data file 1 : 20140592.dat
 antenna height (m)   1.378

met values used:    pressure(mb)            1010.0
                    temperature(deg C)        20.0   h - meteorological data
                    relative humidity(%)      50.0

  x (m)   -2713023.277     lat  (dms)  N    39     7   57.13720
  y (m)   -4145293.358     elon (dms)  E   236    47   45.39187
  z (m)    4003847.775     wlon (dms)  W   123    12   14.60813
                           ht (m)          168.8847
 Message file for station 2
..........................................................
Station ID: 2002  Session #: 059-2   Feb 29, 1988 07:21
Reference Position - LOW ACCURACY:
Lat.= 39:12'30.000"N  Long.=123:10'30.000"W Height=244.0 [meters]
Antenna height = 0.1201 [meters] (entered in the field in feet)
Receiver serial # = 4604                     k - station information
Antenna serial # = 108 (entered in the office)

Survey schedule mode     = AUTOMATIC
Data-logging start time = 07:23               j - data logging time
Data-logging stop  time = 09:32
```

Figure D-8. (Sheet 2 of 13)

```
          Ch0    Ch1    Ch2    Ch3    Ch4    Ch5    Ch6    Ch7    Ch8    Ch9
SVs         3      6      8      9     11     12     13      0      0      0
# meas    356     78     41    392    457    515    515      0      0      0
# cont    356     65     41    381    457    515    515      0      0      0

SV Selection mode = MANUAL SELECTION              e - type of satellite
Elevation mask    = 20      [degrees]  Minimum # of SVs = 4   selection
                       f - elevation mask    g - minimum # of satellite
4 SV Position      Best PDOP Position [ 3.5]   Mean Position [358] used
Latitude:            39:11'36.62852" N            39:11'36.67782" N
Longitude:          123:11'00.34360" W           123:11'00.44659" W
                           251.8                        247.9

3 SV Position      Best PDOP Position [ 2.5]   Mean Position [157]
Latitude:            39:11'36.93995" N            39:11'36.76322" N
Longitude:          123:11'00.75300" N           123:11'00.69634" W
.....................................................................
  STATION (mark) 2

input data fle   1 : 20020592.dat                k - station information
 antenna height (m)        .120
met values used:    pressure(mb)          1010.0
                    temperature(deg C)      20.0  h - meteorological data
                    relative humidity(%)    50.0

  x (m)   -2709224.288      lat  (dms)  N   39       7   36.66538
  y (m)   -4142739.316      elon (dms)  E  236      48   59.56686
  z (m)    4009144.597      wlon (dms)  W  123      11     .43314
                            ht   (m)       244.2261

slope distance (m)      7000.8406    sigma (m)     .032
normal section azimuth (dms) 14 43 50.71
vertical angle (dms)          0 35  6.35

 east(m)    north(m)    up(m)     1780.060    6770.280    71.490 m - solution file
Delta lat(dms)    0    3    39.52817
Delta lon(dms)    0    1    14.17498
Delta ht(m)     75.3413

Vector covariance matrix (m**2) :
                          dx                       dy                    dz
    dx   .293867564477D-02
    dy -.241348364603D-02    .463858449191D-02
    dz -.669428866095D-03  -.252458261144D-03   .689895896357D-03
 correlations
            dx       dy       dz
    dx   1.000
    dy   -.654    1.000
    dz   -.470    -.141    1.000
                          Solution          Sigma
    dx (m)                3798.989           .054
    dy (m)                2554.042           .068
    dz (m)                5296.822           .026
Interval between epochs (sec)    150
Epoch increment      5                            n - epoch intervals
Number of measurements used in solution   168     o - number of epochs
Number of measurements rejected             1
```

Figure D-8. (Sheet 3 of 13)

```
 RMS (cycles)          .033                     1 - RMS

 Elevation mask (deg)       15.0
 Edit multiplier        3.5
 Modified Hopfield troposphere model used

Best tracking C/A code positions
Station 1                                              m - solution files
Pdop          3.1
  x (m)     -2713023.862    lat  (dms)  N   39  7  57.13720
  y (m)     -4145294.253    elon (dms)  E  236 47  45.39187
  z (m)      4003848.645    wlon (dms)  W  123 12  14.60813
                            ht  (m)         170.2629
clock offset(s)         .43266808D-03
freq offset(s/s)       -.11042348D-08

 Code calibration(m)  Carrier calibration(m)
1 -  2          .2520                    .0012
1 -  3          .0552                   -.0006
1 -  4         -.0249                   -.0007
1 -  5          .9292                   -.0008
1 -  6         -.2124                   -.0010
1 -  7         -.0181                   -.0005
1 -  8         -.1875                   -.0009
1 -  9         -.1875                   -.0012
1 - 10         1.0630                   -.0014
Station 2                                              m - solution files
Pdop         2.5
  x (m)     -2709227.033    lat  (dms)  N   39 11  37.11338
  y (m)     -4142726.880    elon (dms)  E  236 48  59.18749
  z (m)      4009155.162    wlon (dms)  W  123 11    .81251
                            ht  (m)         244.0000
clock offset(s)         .88584966D-03
freq offset(s/s)        .58827784D-09

 Code calibration(m)  Carrier calibration(m)
1 -  2          .2021                    .0007
1 -  3         -.3682                   -.0011
1 -  4         -.4199                   -.0010
1 -  5         -.5342                   -.0013
1 -  6         -.5234                   -.0011
1 -  7         -.2754                   -.0002
1 -  8         -.6040                   -.0014
1 -  9         -.8003                   -.0020
1 - 10         -.6953                   -.0017
```

Figure D-8. (Sheet 4 of 13)

```
                         TRIMBLE NAVIGATION, LTD.
                          585 NORTH MARY AVENUE
                       SUNNYVALE, CALIFORNIA 94086
                                  U.S.A.

                             PROGRAM TRIMVEC
                     GPS RELATIVE POSITIONING SOLUTION
                              VERSION 88.028
                                                  a - listing of filename
 File name: 14022059.flt
Coordinate system - WGS-84                        b - type of solution

Type solution:  Triple difference                 i - session time

Start date/time: 1988/ 2/29  7:26:30  day of year 60  tow 113190.
Stop  date/time: 1988/ 2/29  9:32:30  day of year 60  tow 120750.

Data available                                    c - satellite availability

station:  1
sat: 6 :......................                                    :
sat: 8 :....                                                      :
sat: 9 :..........................................................:
sat:11 :..................................................        :
sat:12 :..........................................................:
sat:13 :..........................................................:
sat: 3 :                ..........................................:

station:  2
sat: 6 :.........                                                 :
sat: 8 :....                                                      :
sat: 9 :..................................... .                    :
sat:11 :................................................          :
sat:12 :..........................................................:
sat:13 :..........................................................:
sat: 3 :                  ........................................:

 Ephemeris file used: 20140592.eph                d - ephemeris file used

SATELLITE    AODE(hr.)     HEALTH   WEEK NO.     TOW(sec)    URA(m)
     6          3.41          0        425      113040.00       5.7
     8          4.55          0        425      113040.00     999.0
     9          7.96          0        425      112770.00       4.0
    11          3.98          0        425      112770.00       2.8
    12          6.26          0        425      112770.00       5.7
    13          4.55          0        425      112770.00      16.0
     3          7.40          0        425      114570.00       2.0

Broadcast satellite clock correction values       c - satellite availability
 prn        af0                 af1                 af2            toc
   6 -.8698371239D-03 -.1784883352D-10 -.2775557562D-16 .1188D+06
   8  .4412536509D-03 -.7498783816D-09 -.2775557562D-16 .1188D+06
   9  .2129529630D-03  .1354242053D-11 -.2775557562D-16 .1188D+06
  11 -.9965850040D-04 -.4888534022D-11  .0000000000D+00 .1188D+06
  12  .6357054226D-03  .5343281373D-11  .0000000000D+00 .1188D+06
  13  .3238730133D-03  .2273736754D-11  .0000000000D+00 .1188D+06
   3  .4011737183D-03 -.6821210263D-12  .0000000000D+00 .1188D+06
```

Figure D-8. (Sheet 5 of 13)

```
 Message file for station 1
 .............................................................
Station ID: 2014  Session #: 059-2   Feb. 29, 1988 07:24
Reference Position - HIGH ACCURACY:
Lat.= 39:07'57.401"N  Long.=123:12'14.788"W Height=190.2 [meters]
Antenna height = 1.4387 [meters] (entered in the field in feet)
Receiver serial # = 4604
Antenna serial # = 110 (entered in the office)
                                                  k - station information
Survey schedule mode     = AUTOMATIC
Data-logging start time = 07:26
Data-logging stop  time = 09:33   j - data logging time   c - satellite
                                                               availability
         Ch0   Ch1   Ch2   Ch3   Ch4   Ch5   Ch6   Ch7   Ch8   Ch9
SVs        3     6     8     9    11    12    13     0     0     0
# meas   379   170    28   506   445   506   506     0     0     0
# cont   379   170    28   506   445   506   506     0     0     0

SV Selection mode = MANUAL SELECTION          e -type of satellite
Elevation mask    = 20       [degrees]  Minimum # of SVs = 4  selection
                        f - elevation mask      g - minimum # of satellite
4 SV Position        Best PDOP Position [ 3.1]     Mean Position [497]  used
Latitude:              39:07'57.17388" N             39:07'57.14899" N
Longitude:            123:12'14.47260" W            123:12'14.64029" W
Height [m]:                     169.0                         170.3

3 SV Position        Best PDOP Position [ 2.5]     Mean Position [9]
Latitude:              39:07'57.62620" N             39:07'57.51783" N
Longitude:            123:12'14.95426" N            123"12'14.88427" N
 ............................................................
Origin of station 1 coordinates: Best C/A code tracking solution
   STATION (mark) 1
                                              k - station information
input data file 1 : 20140592.dat
 antenna height (m)    1.378

met values used:   pressure(mb)            1010.0
                   temperature(deg C)        20.0   h - meteorological data
                   relative humidity(%)      50.0

 x (m)     -2713023.277     lat  (dms)  N     39      7   57.13720
 y (m)     -4145293.358     elon (dms)  E    236     47   45.39187
 z (m)      4003847.775     wlon (dms)  W    123     12   14.60813
                            ht  (m)          168.8847
 Message file for station 2
 .............................................................
Station ID: 2002  Session #: 059-2   Feb 29, 1988 07:21
Reference Position - LOW ACCURACY:
Lat.= 39:12'30.000"N  Long.=123:10'30.000"W Height=244.0 [meters]
Antenna height = 0.1201 [meters] (entered in the field in feet)
Receiver serial # = 4606                      k - station information
Antenna serial # = 108 (entered in the office)

Survey schedule mode     = AUTOMATIC
Data-logging start time = 07:23               j - data logging time
Data-logging stop time  = 09:32
```

Figure D-8. (Sheet 6 of 13)

```
        Ch0    Ch1    Ch2    Ch3    Ch4    Ch5    Ch6    Ch7    Ch8    Ch9
SVs       3      6      8      9     11     12     13      0      0      0
# meas  356     78     41    392    457    515    515      0      0      0
# cont  356     65     41    381    457    515    515      0      0      0

SV Selection mode = MANUAL SELECTION    e - type of satellite selection
Elevation mask    = 20     (degrees)  Minimum # of SVs = 4
                                f - elevation mask   g - minimum # of satellite used
4 SV Position       Best PDOP Position [ 3.5]     Mean Position [358]
Latitude:             39:11'36.62852" N             39:11'36.67782" N
Longitude:          123:11'00.34360" W            123:11'00.44659" W
Height [m]:                   251.8                          247.9
                           k - station information
3 SV Position       Best PDOP Position [ 2.5]     Mean Position [157]
Latitude:             39:11'36.93995" N             39:11'36.76322" N
Longitude:          123:11'00.75300" W            123:11'00.69634" W
 ............................................................
  STATION (mark) 2
input data file 1 : 20020592.dat                k - station information
 antenna height (m)      .120
met values used:   pressure(mb)          1010.0
                   temperature(deg C)      20.0    h - meteorological data
                   relative humidity(%)    50.0
  x (m)   -2709224.255      lat  (dms)  N   39     11    36.66472
  y (m)   -4142739.375      elon (dms)  E  236     48    59.56932
  z (m)    4009144.596      wlon (dms)  W  123     11      .43068
                            ht   (m)        244.2494

slope distance (m)      7000.8363    sigma (m)     .036
normal section azimuth (dms) 14 43 52.54
vertical angle (dms)           0 35  7.03

 east(m)   north(m)   up(m)    1780.120    6770.360    71.514  m - solution file
Delta lat(dms)       0   3    39.52751
Delta lon(dms)       0   1    14.17745
Delta ht(m)      75.3647

Vector covariance matrix (m**2) :
                              dx                   dy
    dx  .441035064208D-02
    dy -.450901919640D-02  .575064973739D-02
    dz -.118686476647D-02  .787301206000D-03   .689846755147D-03
correlations:
           dx     dy     dz trop bias1 bias2 bias3 bias4 bias5 bias6
bias7
    dx 1.000
    dy -.895 1.000
    dz -.680  .395 1.000
  trop  .000  .000  .000 1.000
 bias1  .000  .000  .000  .000 1.000
 bias2  .587 -.667 -.394  .000  .000 1.000
 bias3  .925 -.836 -.683  .000  .000  .000 1.000
 bias4  .884 -.865 -.679  .000  .000  .000  .000 1.000
 bias5  .972 -.919 -.675  .000  .000  .000  .000  .000 1.000
 bias6  .969 -.912 -.687  .000  .000  .000  .000  .000  .000 1.000
 bias7  .000  .000  .000  .000  .000  .000  .000  .000  .000  .000
 1.000
```

Figure D-8. (Sheet 7 of 13)

```
                    Solution      Sigma  Sensitivity to 10 meter error
                                             in station 1 coordinates
    dx (m)          3799.022       .066      9.996      .001      .002
    dy (m)          2553.984       .076       .003     9.998     -.006
    dz (m)          5296.821       .026       .004      .002     9.999
  trop (%)              .000       .000       .000      .000      .000
bias 1 (cycle)          .000       .000       .000      .000      .000
bias 2 (cycle)          .098       .272      -.025      .005      .015
bias 3 (cycle)         -.000       .271      -.020      .004      .017
bias 4 (cycle)          .025       .294      -.028      .008      .019
bias 5 (cycle)          .112       .572      -.039      .012      .038
bias 6 (cycle)          .086       .537      -.038      .012      .035
bias 7 (cycle)          .000       .212       .000      .000      .000
 Interval between epochs (sec)  120
 Epoch increment       4
 Number of measurements used in solution    167
 Number of measurements rejected             50
 RMS (cycles)          .020                        1 - RMS
 Elevation mask (deg)     15.0
 Edit multiplier           3.5
 Modified Hopfield troposphere model used
Best tracking C/A code positions
Station 1                                        m - solution files
Pdop         3.1
  x (m)     -2713023.862   lat  (dms)  N   39  7  57.13720
  y (m)     -4145294.253   elon (dms)  E  236 47  45.39187
  z (m)      4003848.645   wlon (dms)  W  123 12  14.60813
                           ht  (m)          170.2629
clock offset(s)        .43266808D-03
freq offset(s/s)     -.11042348D-08
 Code calibration(m)  Carrier calibration(m)
1 -  2          .2520                    .0012
1 -  3          .0552                   -.0006
1 -  4         -.0249                   -.0007
1 -  5          .9292                   -.0008
1 -  6         -.2124                   -.0010
1 -  7         -.0181                    .0005
1 -  8         -.1875                   -.0009
1 -  9         -.1875                   -.0012
1 - 10         1.0630                   -.0014
Station 2                                        m - solution files
Pdop        2.5
 x (m)     -2709227.033      lat   (dms)  N   39    11    37.11338
 y (m)     -4142726.880      elon  (dms)  E  236    48    59.18749
 z (m)      4009155.162      wlon  (dms)  W  123    11      .81251
                             ht  (m)          244.0000
clock offset(s)          .88584966D-03
freq  offset(s/s)        .58827784D-09
 Code calibration(m)  Carrier calibration(m)
1 -  2          .2021                    .0007
1 -  3         -.3682                   -.0011
1 -  4         -.4199                   -.0010
1 -  5         -.5342                   -.0013
1 -  6         -.5234                   -.0011
1 -  7         -.2754                   -.0002
1 -  8         -.6040                   -.0014
1 -  9         -.8003                   -.0020
1 - 10         -.6953                   -.0017
```

Figure D-8. (Sheet 8 of 13)

```
                         TRIMBLE NAVIGATION, LTD.
                          585 NORTH MARY AVENUE
                       SUNNYVALE, CALIFORNIA 94086
                                 U.S.A.

                             PROGRAM TRIMVEC
                    GPS RELATIVE POSITIONING SOLUTION
                             VERSION 88.028
                                                    a - listing of the filename
 File name: 14022059.fix
Coordinate system - WGS-84                          b - type of solution

Type solution:  Double difference                   i - sessiontime

Start date/time: 1988/ 2/29  7:26:30  day of year 60  tow 113190.
Stop  date/time: 1988/ 2/29  9:32:30  day of year 60  tow 120750.

Data available                                      c - satellite availability

station:  1
sat: 6 :.....................                                         :
sat: 8 :....                                                          :
sat: 9 :..............................................................:
sat:11 :...............................................               :
sat:12 :..............................................................:
sat:13 :..............................................................:
sat: 3 :               ...............................................:

station:  2
sat: 6 :........                                                      :
sat: 8 :....                                                          :
sat: 9 :...................................  .                        :
sat:11 :.......................................                       :
sat:12 :..............................................................:
sat:13 :..............................................................:
sat: 3 :                   ...........................................:

 Ephemeris file used: 20140592.eph                  d - ephemeris file used

SATELLITE    AODE(hr.)     HEALTH  WEEK NO.     TOW(SEC)    URA(M)
     6          3.41          0       425      113040.00      5.7
     8          4.55          0       425      113040.00    999.0
     9          7.96          0       425      112770.00      4.0
    11          3.98          0       425      112770.00      2.8
    12          6.26          0       425      112770.00      5.7
    13          4.55          0       425      112770.00     16.0
     3          7.40          0       425      114570.00      2.0

Broadcast satellite clock correction values         c - satellite availability
 prn         af0                af1                af2            toc
   6 -.8698371239D-03 -.1784883352D-10 -.2775557562D-16 .1188D+06
   8  .4412536509D-03 -.7498783816D-09 -.2775557562D-16 .1188D+06
   9  .2129529630D-03  .1354242053D-11 -.2775557562D-16 .1188D+06
  11 -.9965850040D-04 -.4888534022D-11  .0000000000D+00 .1188D+06
  12  .6357054226D-03  .5343281373D-11  .0000000000D+00 .1188D+06
  13  .3238730133D-03  .2273736754D-11  .0000000000D+00 .1188D+06
   3  .4011737183D-03 -.6821210263D-12  .0000000000D+00 .1188D+06
```

Figure D-8. (Sheet 9 of 13)

```
Message file for station 1
..............................................................
Station ID: 2014   Session #: 059-2   Feb. 29, 1988 07:24
Reference Position - HIGH ACCURACY:
Lat.= 39:07'57.401"N  Long.=123:12'14.788"W Height=190.2 [meters]
Antenna height = 1.4387 [meters] (entered in the field of feet)
Receiver serial # = 4604
Antenna serial # = 110 (entered in the office)
                                              k - station information
Survey schedule mode       = AUTOMATIC
Data-logging start time = 07:26
Data-logging stop  time = 09:33   j - data logging time   c - satellite
                                                               availailabilty
          Ch0   Ch1   Ch2   Ch3   Ch4   Ch5   Ch6   Ch7   Ch8   Ch9
SVs         3     6     8     9    11    12    13     0     0     0
# meas    379   170    28   506   445   506   506     0     0     0
# cont    379   170    28   506   445   506   506     0     0     0

SV Selection mode = MANUAL SELECTION       e - type of satellite
Elevation mask     = 20     [degrees]  Minimum # of SVs = 4  selection
                          f - elevation mask    g - minimum # of satellite
4 SV Position       Best PDOP Position [ 3.1]    Mean Position [497]  used
Latitude:             39:07'57.17388" N            39:07'57.14899" N
Longitude:          123:12'14.47260"W            123:12'14.64029" W
Height [m]:                    169.0                        170.3

3 SV Position       Best PDOP Position [ 2.5]    Mean Position [9]
Latitude:             39:07'57.62620" N            39:07'57.51783" N
Longitude:          123:12'14.95426" N           123"12'14.88427" N
..............................................................
Origin of station 1 coordinates: Best C/A code tracking solution
   STATION (mark) 1
                                              k - station information
input data file 1 : 20140592.dat
 antenna height (m)    1.378

met values used:    pressure(mb)          1010.0
                    temperature(deg C)      20.0   h - meteorological data
                    relative humidity(%)    50.0

x (m)      -2713023.277     lat  (dms)  N    39      7    57.13720
y (m)      -4145293.358     elon (dms)  E   236     47    45.39187
z (m)       4003847.775     wlon (dms)  W   123     12    14.60813
                            ht  (m)          168.8847
 Message file for station 2
..............................................................
Station ID: 2002   Session #: 059-2   Feb 29, 1988 07:21
Reference Position - LOW ACCURACY:
Lat.= 39:12'30.000"N  Long.=123:10'30.000"W Height=244.0 [meters]
Antenna height = 0.1201 [meters] (entered in the field in feet)
Receiver serial # = 4606                      k - station information
Antenna serial # = 108 (entered in the office)

Survey schedule mode       = AUTOMATIC
Data-logging start time = 07:23               j - data logging time
Data-logging  stop time = 09:32
```

Figure D-8. (Sheet 10 of 13)

```
              Ch0    Ch1    Ch2    Ch3    Ch4    Ch5    Ch6    Ch7    Ch8    Ch9
SVs             3      6      8      9     11     12     13      0      0      0
# meas        356     78     41    392    457    515    515      0      0      0
# cont        356     65     41    381    457    515    515      0      0      0

SV Selection mode = MANUAL SELECTION--[e - type of satellite selection]
Elevation mask     = 20      [degrees]   Minimum # of SVs = 4
                       [f - elevation mask]  [g - minimum # of satellite
                                                                    used]
4 SV Position      Best PDOP Position [ 3.5]      Mean Position [358]
Latitude:            39:11'36.62852" N              39:11'36.67782" N
Longitude:         123:11'00.34360" W             123:11'00.44659" W
Height [m]:                   251.8                          247.9
                         k - station information
3 SV Position      Best PDOP Position [ 2.5]      Mean Position [157]
Latitude:            39:11'36.93995" N              39:11'36.76322" N
Longitude:         123:11'00.75300" W             123"11'00.69634" W
.................................................................
  STATION (mark) 2
input data file 1 : 20020592.dat            [k - station information]
 antenna height (m)       .120
met values used:    pressure(mb)            1010.0
                    temperature(deg C)        20.0  [h - meteorological data]
                    relative humidity(%)      50.0
  x (m)    -2709224.271       lat  (dms)  N   39       11      36.66495
  y (m)    -4142739.345       elon (dms)  E  236       48      59.56810
  z (m)     4009144.592       wlon (dms)  W  123       11        .43190
                              ht  (m)          244.2339

slope distance (m)       7000.8355    sigma (m)     .015
normal section azimuth (dms) 14 43 51.65
vertical angle (dms)            0 35   6.58

 east(m)   north(m)    up(m)     1780.090    6770.367    71.498 [m - solution file]
Delta lat(dms)       0  3    39.52775
Delta lon(dms)       0  1    14.17622
Delta ht(m)       75.3491

Vector covariance matrix (m**2) :
                         dx                     dy
    dx  .785657836034D-04
    dy  .673839449077D-04    .723510872927D-03
    dz -.843065752912D-04   -.504546156900D-03    .464958813305D-03
correlations:
           dx      dy      dz trop bias1 bias2 bias3 bias4 bias5 bias6
bias7
    dx 1.000
    dy  .283 1.000
    dz -.680 -.870 1.000
  trop  .000   .000   .000 1.000
 bias1  .000   .000   .000   .000 1.000
 bias2  .000   .000   .000   .000   .000 1.000
 bias3  .000   .000   .000   .000   .000   .000 1.000
 bias4  .000   .000   .000   .000   .000   .000   .000 1.000
 bias5  .000   .000   .000   .000   .000   .000   .000   .000 1.000
 bias6  .000   .000   .000   .000   .000   .000   .000   .000  .000 1.000
 bias7  .000   .000   .000   .000   .000   .000   .000   .000  .000   .000
 1.000
```

Figure D-8. (Sheet 11 of 13)

```
                    Solution      Sigma  Sensitivity to 10 meter error
                                             in station 1 coordinates
     dx (m)         3799.006       .009      9.999      .000     -.002
     dy (m)         2554.013       .027      -.001    10.000     -.001
     dz (m)             .000       .000       .000      .000    10.000
   trop (%)             .000       .000       .000      .000      .000
 bias 1 (cycle)         .000       .000       .000      .000      .000
 bias 2 (cycle)         .000       .000       .000      .000      .000
 bias 3 (cycle)         .000       .000       .000      .000      .000
 bias 4 (cycle)         .000       .000       .000      .000      .000
 bias 5 (cycle)         .000       .000       .000      .000      .000
 bias 6 (cycle)         .000       .000       .000      .000      .000
 bias 7 (cycle)         .000       .000       .000      .000      .000
  Results of integer bias search:
                .0549                1.06578                1.36295
                    0                      1                      0
                    0                      0                      0
                    0                      0                      0
                    0                      0                      0
                    0                      0                      0
                    0                      0                      0
 Ratio sum-of-squares(2) to sum-of-squares(1)          18.87
  Interval between epochs (sec)  120
  Epoch increment        4
  Number of measurements used in solution       161
  Number of measurements rejected                56
  RMS (cycles)          .020                       1 - RMS
  Elevation mask (deg)      15.0
  Edit multiplier            3.5
  Modified Hopfield troposhpere model used
 Best tracking C/A code positions
 Station 1                                         m - solution file
 Pdop          3.1
   x (m)     -2713023.862   lat  (dms)  N   39  7   57.13720
   y (m)     -4145294.253   elon (dms)  E  236 47   45.39187
   z (m)      4003848.645   wlon (dms)  W  123 12   14.60813
                            ht (m)          170.2629
 clock offset(s)          .43266808D-03
 freq offset(s/s)        -.11042348D-08
  Code calibration(m)   Carrier calibration(m)
 1 -  2           .2520                .0012
 1 -  3           .0552               -.0006
 1 -  4          -.0249               -.0007
 1 -  5           .9292               -.0008
 1 -  6          -.2124               -.0010
 1 -  7          -.0181                .0005
 1 -  8          -.1875               -.0009
 1 -  9          -.1875               -.0012
 1 - 10          1.0630               -.0014
 Station 2                                         m - solution file
 Pdop        2.5
   x (m)    -2709227.033    lat   (dms)  N    39  11   37.11338
   y (m)    -4142726.880    elon  (dms)  E   236  48   59.18749
   z (m)     4009155.162    wlon  (dms)  W   123  11     .81251
                            ht (m)             244.0000
 clock offset(s)          .88584966D-03
 freq  offset(s/s)        .58827784D-09
  Code calibration(m)   Carrier calibration(m)
 1 -  2           .2021                .0007
 1 -  3          -.3682               -.0011
 1 -  4          -.4199               -.0010
 1 -  5          -.5342               -.0013
 1 -  6          -.5234               -.0011
 1 -  7          -.2754               -.0002
 1 -  8          -.6040               -.0014
 1 -  9          -.8003               -.0020
 1 - 10          -.6953               -.0017
```

Figure D-8. (Sheet 12 of 13)

```
----------------------------------------------------------------
TRIMVEC GPS RELATIVE POSITIONING SOLUTION SUMMARY: VERSION 88.028

SOLUTION OUTPUT FILE: a:14022059.fix

STATION 1:  Station ID: 2014  Session No.: 059-2  Feb 29,1988
07:24
Data-logging start time = 07:26   Data-logging stop time = 09:33

STATION 2:  Station ID: 2002  Session #: 059-2  Feb 29,1988 07:21
Data-logging start time = 07:23   Data-logging stop time = 09:32

STATION COORDINATES:

Sta       Ant (m)      Latitude            Longitude         Hgt (m)
 1         1.378    39:07'57.13720" N  123:12'14.60813" W  168.885
 2 [TRP]   0.120    39:11'36.66538" N  123:11'00.43314" W  244.226
 2 [FLT]   0.120    39:11'36.66472" N  123:11'00.43068" W  244.249
 2 [FIX]   0.120    39:11'36.66495" N  123:11'00.43190" W  244.234

Origin of station 1 coordinates : Best C/A code tracking solution

 SOLUTION SUMMARY:

Solution      dx (m)        dy (m)     dz(m)       dh (m)      RDOP
TRIPLE       3798.989      2554.042   5296.822     75.341      n/a
FLOAT        3799.022      2553.984   5296.821     75.365      n/a
FIXED        3799.006      2554.013   5296.817     75.349      n/a
FLT-FIX         0.016        -0.029      0.004      0.016

Solution Slope (m)  sig   Epochs/Rejected  Epoch int    Epoch inc
TRIPLE   7000.8406 [0.032]  168/  1        150 (secs)   5 (epochs)
FLOAT    7000.8363 [0.036]  167/ 50        120 (secs)   4 (epochs)
FIXED    7000.8355 [0.015]  161/ 56        120 (secs)   4 (epochs)

Fixed solution quality factor:    18.9
Fixed solution rms:              0.020 (cycles)
Maximum float - fixed delta:       2.0 (cm)

Integers found, RMS is OK, FIXED solution recommended.
----------------------------------------------------------------
```

Figure D-8. (Sheet 13 of 13)

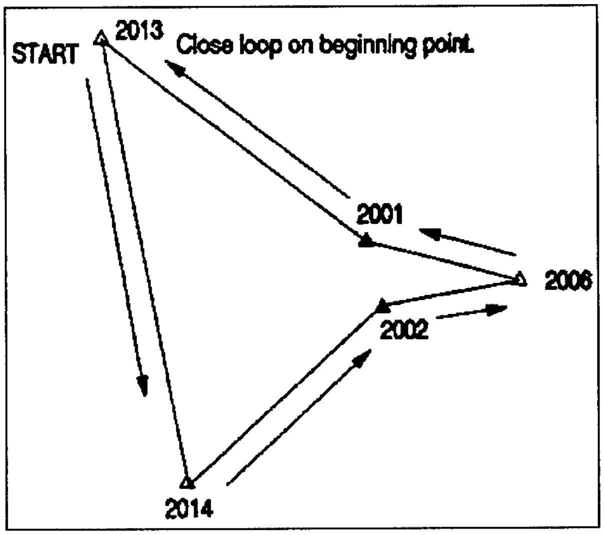


Figure D-9. Loop closure (Ukiah)

a. The input data file for a GEOLAB adjustment is called an "IOB" file. An IOB file can be created using a text editor program or with a GEOLAB option called "GPS Environment." An IOB file is specific to the GEOLAB adjustment software and may or may not be required by other least-square adjustment software (refer to Chapter 11 or the owner's manual). The GEOLAB Environment option takes GPS baseline solution files developed by most GPS manufacturers and automatically sets up an IOB file for adjustment.

b. The IOB input file generally consists of the following information:

(1) *Top line.* Title Record - usually a project name and an adjustment number.

(2) *Second line.* Options Record - this record specifies which GEOLAB options are to be activated for processing.

(3) *Third line.* Ellipsoid Specification Record - Prints ellipsoid parameters chosen in the Options Record or as chosen by the user.

(4) *Station information section.* All stations must have their coordinates defined here. The coordinates must be given as ellipsoidal latitude, longitude, and orthometric height, or as Cartesian coordinates. In this section, stations are either held fixed or are to be adjusted. If stations are not held fixed, estimated coordinates are input.

(5) *Auxiliary parameter definition record.* The auxiliary parameter group definition record is optional, but can be used if GEOLAB is to solve for various scale, orientation, translation, or constant parameters. In the sample GEOLAB input, enough vertical and horizontal control is held fixed to solve for SCALE and ROTATION. Rotation is about the Cartesian X-axis, Y-axis, and Z-axis.

(6) *Observation records section.* In the example GEOLAB input file, only GPS observations are entered. Each baseline is entered separately with the station name and Cartesian coordinate differences between the stations, which is the computed baseline. These can also be entered as $\Delta x=0$, $\Delta y=0$, $\Delta z=0$, for station 1 and the 3D

Baseline	Δ x, m	Δ y, m	Δ z, m	Distance, m
13142059.FIX 2013 -> 2014	-3,367.429	-7,891.019	-10,410.673	13,490.362
14021059.FIX 2014 -> 2002	3,799.005	2,554.018	5,296.798	7,000.823
02053056.FIX 2002 -> 2006	953.294	-748.319	-16.709	1,212.035
06013056.FIX 2006 -> 2001	-666.617	1,441.548	908.280	1,829.593
01132059.FIX 2001 -> 2013	-718.244	4,643.775	4,222.288	6,317.297

baseline for station 2. For example, baseline 1 would be entered as:

STATION		∆x	∆y	∆z
92	2001	0.000	0.000	0.000
92	2006	-666.617	1,441.548	908.280

The correlation matrix elements from the baseline solution are also entered and the last line of the observation record is the standard deviation for ∆x, ∆y, and ∆z.

c. The following figure (Figure D-10) taken from a GEOLAB input is annotated with the convention above.

d. Once an IOB file containing parameters necessary to perform an adjustment has been completed, the adjustment can begin. The first step is to select the baselines needed for the adjustment. The baselines chosen must have been processed adequately, as detailed in Chapter 10, or as recommended by the GPS manufacturer.

e. The example IOB file shown in Figure D-10 was adjusted as shown in Figure D-11. Figure D-11 has been annotated for a general discussion of the results.

f. For the first adjustment (Figure D-11), one point was held fixed in 3D, producing a free adjustment (refer to Chapter 10 for further detail). A free adjustment checks the internal consistency of a GPS survey.

g. A second adjustment (not shown) can be made to check the existing network if these control points are directly tied together with GPS baselines. To do this with GEOLAB, the user must set up an IOB file with only the fixed control and the respective baselines connecting them. Hold fixed all control except one point, then adjust. Next, fix that control point and free one of the others, and keep repeating this procedure until all control points have been allowed to be checked against their true position. If the position of one control point is "bad," that point can generally be omitted from the subsequent constrained adjustment or allowed to adjust with the other points.

h. A final constrained adjustment (Figure D-12) should hold fixed all good horizontal and vertical control. Adjust and check the output as detailed in Chapter 11.

D-6. Check of the Final Adjustment

After each adjustment was run, the 2D and 1D station (absolute) error ellipse for each adjusted point was reviewed (for further discussion on error ellipses and adjustments, refer to Chapter 11). These are listed as major semi-axis, minor semi-axis, major azimuth, and vertical (as shown on page 15 of the free adjustment and page 16 of the constrained adjustment).[1] The size of the error ellipses listed in this portion of the GEOLAB adjustment are an indication of the internal consistency of the GPS survey. The smaller the size of the ellipse, the better the survey. The size of the ellipse will also generally become larger as the project size increases. In the constrained adjustment shown, the major semi-axis and minor semi-axis are of the millimeter level (0.0066 and 0.0048 mm for 2001 and 0.0062 and 0.0044 mm for 2002, respectively) - which is acceptable.

a. The 2D and 1D relative error ellipses and line accuracies (i.e., precision) between survey points were checked. These are listed as major semi-axis, minor semi-axis, major azimuth, and vertical, spatial distance, and precision (as shown on page 16 of the free adjustment and page 17 of the constrained adjustment). When checking these values, one should remember they are relative values. The relativity of points used in the adjustment can sometimes produce deceptive values, higher major semi-axis and minor semi-axis values: this may occur between points that are close together, but have not been tied together by a baseline. Because of the possibility of the production of deceptive results, the user must take special care when reviewing these values. In the constrained adjustment shown, the major semi-axis and minor semi-axis are of the millimeter level (0.0045 and 0.0036 for the baseline 2001->2002). The project precision in parts per million (PPM) is also listed in this portion of the adjustment and should be checked.

b. The histograms in the GEOLAB adjustments were reviewed. The histogram is a visual representation of the standardized (normalized) residuals. The histogram shows whether the residuals are symmetrical about the mean residual, the total spread of values of the residuals, the frequencies of the different values, and how peaked or how flat the distribution of the residuals may be. A generally good looking histogram has data that, when graphed, is in the shape of a bell curve.

c. The free adjustment line accuracy precessions shown on page 16 of Figure D-11 are the primary criteria used to evaluate the survey adequacy. The worst precision (4.182 ppm between 2001 and 2013) equates to 1:239,000. This far exceeds the required project accuracy

[1] Note the page numbers listed on the right side of the sheets of Figures D-11 and D-12. Each sheet contains several pages of the GEOLAB adjustments.

```
COYOTE DAM CONTROL
0  0 21            001 0 1 0              00 010100    0.001 95.000
 80    6378137.000  298.2572221011 0.000       0.000          0.000

 24   2001                 -2708942.23500 -4142043.83100  4010047.0300
 14   2006                       N39 11 34.37462W123 10 10.28988 366.0850
 24   2002                 -2709230.74000 -4142726.83300  4009152.53400
 14   2014                       N39  7 57.41258W123 12 14.77684 190.1700
 14   2015                       N39 15 12.11624W123 13 17.48887 222.8350
 943DDWGSXX                SCAL ROTX ROTY ROTZ
      baseline#  1           day  57      01063056.FIX             type 10

 913DD
 92   2001                    -2708942.235    -4142043.831    4010047.030
 92   2006                    -2708275.618    -4143485.379    4009138.750
 943DDWGSXX
 97PDCUPPER
 98        1             0.5690        -0.6230
 98        1            -0.6310
 98        0.005000     0.006000      0.004000
           ]
      baseline#  2           day  57      02063056.FIX             type 10

 913DD
 92   2002                    -2709230.740    -4142726.833    4009152.534
 92   2006                    -2709227.764    -4143475.151    4009135.824
 943DDWGSXX
 97PDCUPPER
 98        1             0.3900        -0.6720
 98        1            -0.4460
 98        1
 98        0.003000     0.005000      0.004000
           ]
           baseline#  3      day  59      01022058.FIX             type 10

 913DD
 92   2001                    -2708941.095    -4142050.632    4010039.950
 92   2002                    -2709227.764    -4142743.851    4009149.248
 943DDWGSXX
 97PDCUPPER
 98        1             0.5190        -0.5760
 98        1            -0.7560
 98        1
 98        0.003000     0.004000      0.004000
           ]
           baseline#  4      day  59      01023058.FIX             type 10

 913DD
 92   2001                   -2708946.108     -4142048.218    4001039.950
 92   2002                   -2709232.787     -4142741.441    4009148.372
 943DDWGSXX
 97PDCUPPER
 98        1             0.6130        -0.7240
 98        1            -0.6180
 98        1
 98        0.004000     0.004000      0.004000
           ]
           baseline#  5      day  60      14021059.FIX             type 10

 913DD
```

Figure D-10. GEOLAB input (Ukiah) (Continued)

```
92  2014            -2713050.517    -4145286.831    4003867.585
92  2002            -2709251.512    -4142732.813    4009164.383
943DDWGSXX
97PDCUPPER
98      1          0.5930      -0.2650
98      1         -0.7720
98      1
98      0.018000  0.016000     0.020000
        ]
    baseline# 6       day  60      13142059.FIX          type 10

913DD
92  2013            -2709663.600    -4137421.450    4014263.662
92  2014            -2713031.029    -4145312.470    4003852.989
943DDWGSXX
97PDCUPPER
98      1          0.1480      -0.2650
98      1         -0.8850
98      1
98      0.015000  0.046000     0.033000
        ]
    baseline# 7       day  60      13012059.FIX          type 10

913DD
92  2013            -2709663.600    -4137421.450    4014263.662
92  2001            -2708945.356    -4142065.225    4010041.375
943DDWGSXX
97PDCUPPER
98      1          0.4380      -0.5290
98      1         -0.9090
98      1
98      0.007000  0.020000     0.015000
        }
99
```

Figure D-10. (Concluded)

```
                 U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                   COYOTE DAM FREE ADJUSTMENT  NAD-83
--------------------------------------------------------------------
 A=  6378137.000 B=  6356752.314 X0=       0.000 Y0=       0.000 Z0=        0.000
--------------------------------------------------------------------
PREPARE:       ASCII input file: <coyote_2.iob>.
PREPARE successfully completed.
------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]      Page      0
--------------------------------------------------------------------
--------------------------------------------------------------------
GETUP:
-------------------------------------------------------------------
|          PARAMETERS              |          OBSERVATIONS           |
|------------------------------------------------------------------|
| Description    |     Number      | Description     |    Number    |
|------------------------------------------------------------------|
| All Stations   |          5      | Directions       |         0    |
| Fixed Stations |          1      | Distances        |         0    |
| Free 3-D Stations|        4      | Azimuths         |         0    |
| Free 2-D Stations|        0      | Vertical Angles  |         0    |
| Free 1-D Stations|        0      | Zenithal Angles  |         0    |
| Coord. Parameters|       12      | Angles           |         0    |
| Astro. Latitudes |        0      | Heights          |         0    |
| Astro. Longitudes|        0      | Height Differences|        0    |
| Geoid Records  |          0      | Auxiliary Params.|         0    |
| All Aux. Pars. |          0      | 2-D Coords.      |         0    |
| Direction Pars.|          0      | 2-D Coord. Diffs.|         0    |
| Scale Parameters|         0      | 3-D Coords.      |         0    |
| Constant Pars. |          0      | 3-D Coord. Diffs.|        21    |
| Rotation Pars. |          0      |                  |              |
| Translation Pars.|        0      |                  |              |
|                |                 |                  |              |
|                |   --------      |                  |  --------    |
| Total Parameters|        12      | Total Observations|       21    |
|------------------------------------------------------------------|
|                  Degrees of Freedom =        9                    |
-------------------------------------------------------------------
--------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]      Page      1
--------------------------------------------------------------------
                      SUMMARY  OF  SELECTED  OPTIONS
--------------------------------------------------------------------
     OPTION                          |     SELECTION
-------------------------------------|------------------------------
     Computation Mode                |     Adjustment
     Linear Unit                     |     Metre
     Maximum Iterations              |     2
     Confidence Regions Selected     |     All
     Confidence Region Dimensions    |     1-D, 2-D, and 3-D
     Print Input Station Data        |     On
     Variance Factor Knowledge       |     Known
     Confidence Level for Statistics |     95.000
     Dual-Height Mode                |     Off
     Print Solution Vector           |     On All Iterations
     Printed Ellipsoidal Coordinates |     5 Decimal Places
     Print Adjusted X, Y, Z          |     On
     Print Histograms                |     On
     Print Misclosures               |     On All Iterations
     Print Residuals                 |     All
     Variance Factor Usage           |     Scale Confidence Regions
     Residual Rejection Criterion    |     Tau Max
     Angular Misclosure Limit Factor |     10
     Linear Misclosure Limit Factor  |     10
     Convergence Criterion           |     0.001000
--------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]      Page      2
```

Figure D-11. GEOLAB adjustment output (free) (Sheet 1 of 7)

U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
COYOTE DAM FREE ADJUSTMENT
A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

CODE	IDENT.	DESCRIPTOR	INITIAL VALUES		
14	2006				
		ELLIPSOIDAL :	39 11 34.37462	-123 10 10.28988	336.0850
		ASTRONOMIC :	39 11 34.37462	-123 10 10.28988	336.0850
		GEOIDAL :	0 0 0.00000	0 0 0.00000	0.0000
		CARTESIAN :	-2708280.4788	-4143494.7721	4009147.8933
24	2001				
		ELLIPSOIDAL :	39 12 14.43422	-123 11 6.45941	243.8658
		ASTRONOMIC :	39 12 14.43422	-123 11 6.45941	243.8658
		GEOIDAL :	0 0 0.00000	0 0 0.00000	0.0000
		CARTESIAN :	-2708942.2350	-4142043.8310	4010047.0300
24	2002				
		ELLIPSOIDAL :	39 11 37.00656	-123 11 0.94286	243.8815
		ASTRONOMIC :	39 11 37.00656	-123 11 0.94286	243.8815
		GEOIDAL :	0 0 0.00000	0 0 0.00000	0.0000
		CARTESIAN :	-2709230.7400	-4142726.8330	4009152.5340
24	2014				
		ELLIPSOIDAL :	39 7 57.44196	-123 12 15.70589	188.7219
		ASTRONOMIC :	39 7 57.44196	-123 12 15.70589	188.7219
		GEOIDAL :	0 0 0.00000	0 0 0.00000	0.0000
		CARTESIAN :	-2713050.5170	-4145286.8310	4003867.5850
24	2013				
		ELLIPSOIDAL :	39 15 11.55819	-123 13 17.15396	220.5009
		ASTRONOMIC :	39 15 11.55819	-123 13 17.15396	220.5009
		GEOIDAL :	0 0 0.00000	0 0 0.00000	0.0000
		CARTESIAN :	-2709663.6000	-4137421.4500	4014263.6620

GETUP successfully completed.

GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696] Page 3

FORMEQ: NOTE 6: Reordering was done.

AT	TO	OBS TYPE	OBSERVATION	APPROX.SIG.	MISCLOSURE
2001	2006	3-D X-Coord Diff	666.6170	0.0037	-4.8608
2001	2006	3-D Y-Coord Diff	-1441.5480	0.0045	-9.3931
2001	2006	3-D Z-Coord Diff	-908.2800	0.0028	9.1433
2002	2006	3-D X-Coord Diff	953.2950	0.0022	-3.0338
2002	2006	3-D Y-Coord Diff	-748.3180	0.0044	-19.6211
2002	2006	3-D Z-Coord Diff	-16.7100	0.0029	12.0693
2001	2002	3-D X-Coord Diff	-286.6690	0.0024	-1.8360
2001	2002	3-D Y-Coord Diff	-693.2190	0.0026	10.2170
2001	2002	3-D Z-Coord Diff	-891.5890	0.0025	-2.9070
2001	2002	3-D X-Coord Diff	-286.6790	0.0026	-1.8260
2001	2002	3-D Y-Coord Diff	-693.2230	0.0030	10.2210
2001	2002	3-D Z-Coord Diff	-891.5780	0.0026	-2.9180
2014	2002	3-D X-Coord Diff	3799.0050	0.0129	20.7720
2014	2002	3-D Y-Coord Diff	2554.0180	0.0101	5.9800
2014	2002	3-D Z-Coord Diff	5296.7980	0.0113	-11.8490
2013	2014	3-D X-Coord Diff	-3367.4290	0.0142	-19.4880
2013	2014	3-D Y-Coord Diff	-7891.0200	0.0210	25.6390
2013	2014	3-D Z-Coord Diff	-10410.6730	0.0147	14.5960
2013	2001	3-D X-Coord Diff	718.2440	0.0059	3.1210
2013	2001	3-D Y-Coord Diff	-4643.7750	0.0083	21.3940
2013	2001	3-D Z-Coord Diff	-4222.2870	0.0059	5.6550

FORMEQ successfully completed.

GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696] Page 4

Figure D-11. (Sheet 2 of 7)

```
---------------------------------------------------------------------------
                  U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                         COYOTE DAM       FREE ADJUSTMENT
A= 6378137.000 B= 6356752.314 X0=       0.000 Y0=       0.000 Z0=       0.000
---------------------------------------------------------------------------
SOLVE:           Solution (Iteration Count = 1):
CODE IDENT.   TYPE                 INITIAL             DX              UPDATED
---- -------- --------- ----------------- ------------ -------------------
 24  2001     LATITUDE     39  12  14.43422      0.01413    39  12  14.44836
 24  2001     LONGITUDE  -123  11   6.45941      0.04476  -123  11   6.41465
 24  2001     HEIGHT              243.86577     13.93969            257.80546

 24  2002     LATITUDE     39  11  37.00656     -0.06729    39  11  36.93927
 24  2002     LONGITUDE  -123  11   0.94286      0.34171  -123  11   0.60115
 24  2002     HEIGHT              243.88154     21.63376            265.51530

 24  2014     LATITUDE     39   7  57.44196     -0.02938    39   7  57.41258
 24  2014     LONGITUDE  -123  12  15.70589      0.92905  -123  12  14.77684
 24  2014     HEIGHT              188.72193      1.44519            190.16712

 24  2013     LATITUDE     39  15  11.55819      0.55805    39  15  12.11624
 24  2013     LONGITUDE  -123  13  17.15396     -0.33491  -123  13  17.48887
 24  2013     HEIGHT              220.50094      2.33476            222.83570
SOLVE successfully completed.
---------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]      Page     5
---------------------------------------------------------------------------

---------------------------------------------------------------------------
FORMEQ:          FORMEQ successfully completed.
---------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]      Page     6
---------------------------------------------------------------------------

---------------------------------------------------------------------------
SOLVE:           Adjusted Values (Iteration Count = 2):
CODE IDENT.   TYPE                 INITIAL             DX             ADJUSTED
---- -------- --------- ----------------- ------------ -------------------
 14  2006     LATITUDE     39  11  34.37462        FIXED
 14  2006     LONGITUDE  -123  10  10.28988        FIXED
 14  2006     HEIGHT              336.08500        FIXED

 24  2001     LATITUDE     39  12  14.44836     -0.00000    39  12  14.44836
 24  2001     LONGITUDE  -123  11   6.41465     -0.00000  -123  11   6.41465
 24  2001     HEIGHT              257.80546     -0.00000            257.80546

 24  2002     LATITUDE     39  11  36.93927      0.00000    39  11  36.93927
 24  2002     LONGITUDE  -123  11   0.60115     -0.00000  -123  11   0.60115
 24  2002     HEIGHT              265.51530      0.00001            265.51530

 24  2014     LATITUDE     39   7  57.41258     -0.00000    39   7  57.41258
 24  2014     LONGITUDE  -123  12  14.77684     -0.00000  -123  12  14.77684
 24  2014     HEIGHT              190.16712      0.00004            190.16716

 24  2013     LATITUDE     39  15  12.11624     -0.00000    39  15  12.11624
 24  2013     LONGITUDE  -123  13  17.48887     -0.00000  -123  13  17.48887
 24  2013     HEIGHT              222.83570      0.00003            222.83573
---------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]      Page     7
---------------------------------------------------------------------------

                       Adjusted Cartesian Coordinates:
CODE IDENT.       X-COORDINATE     Y-COORDINATE      Z-COORDINATE
---- -------- ---------------- ---------------- ----------------
 24  2001        -2708947.0978    -4142053.2284     4010056.1788
 24  2002        -2709233.7714    -4142746.4510     4009164.5970
 24  2014        -2713032.7730    -4145300.4675     4003867.7943
 24  2013        -2709665.3421    -4137409.4529     4014278.4662
SOLVE successfully completed.
---------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]      Page     8
```

Figure D-11. (Sheet 3 of 7)

U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
COYOTE DAM FREE ADJUSTMENT
A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

INVERT: INVERT successfully completed.

GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696] Page 9

RESID:

STATION	3-D COORD DIFFS	STD.DEV.	RESIDUAL	STD.DEV.	STAN.RES.
2001	-2708942.2350				
	-4142043.8310				
	4010047.0300				
2006	-2708275.6180	0.0050	0.0020	0.0040	0.4913
	-4143485.3790	0.0060	0.0043	0.0044	0.9722
	4009138.7500	0.0040	-0.0055	0.0026	-2.1131
	End of Observation Set				
2002	-2709230.7400				
	-4142726.8330				
	4009152.5340				
2006	-2708277.4450	0.0030	-0.0024	0.0015	-1.5684
	-4143475.1510	0.0050	-0.0031	0.0031	-1.0050
	4009135.8240	0.0040	0.0063	0.0026	2.4021
	End of Observation Set				
2001	-2708941.0950				
	-4142050.6320				
	4010040.8370				
2002	-2709227.7640	0.0030	-0.0046	0.0020	-2.2695
	-4142743.8510	0.0040	-0.0036	0.0031	-1.1723
	4009149.2480	0.0040	0.0072	0.0032	2.2790
	End of Observation Set				
2001	-2708946.1080				
	-4142048.2180				
	4010039.9500				
2002	-2709232.7870	0.0040	0.0054	0.0033	1.6114
	-4142741.4410	0.0040	0.0004	0.0031	0.1290
	4009148.3720	0.0040	-0.0038	0.0032	-1.1996
	End of Observation Set				
2014	-2713050.5170				
	-4145286.8310				
	4003867.5850				
2002	-2709251.5120	0.0180	-0.0034	0.0132	-0.2586
	-4142732.8130	0.0160	-0.0015	0.0077	-0.1983
	4009164.3830	0.0200	0.0047	0.0129	0.3661
	End of Observation Set				
2013	-2709663.6000				
	-4137421.4500				
	4014263.6620				
2014	-2713031.0290	0.0150	-0.0019	0.0092	-0.2019
	-4145312.4700	0.0460	0.0054	0.0407	0.1332
	4003852.9890	0.0330	0.0011	0.0275	0.0389

GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696] Page 10

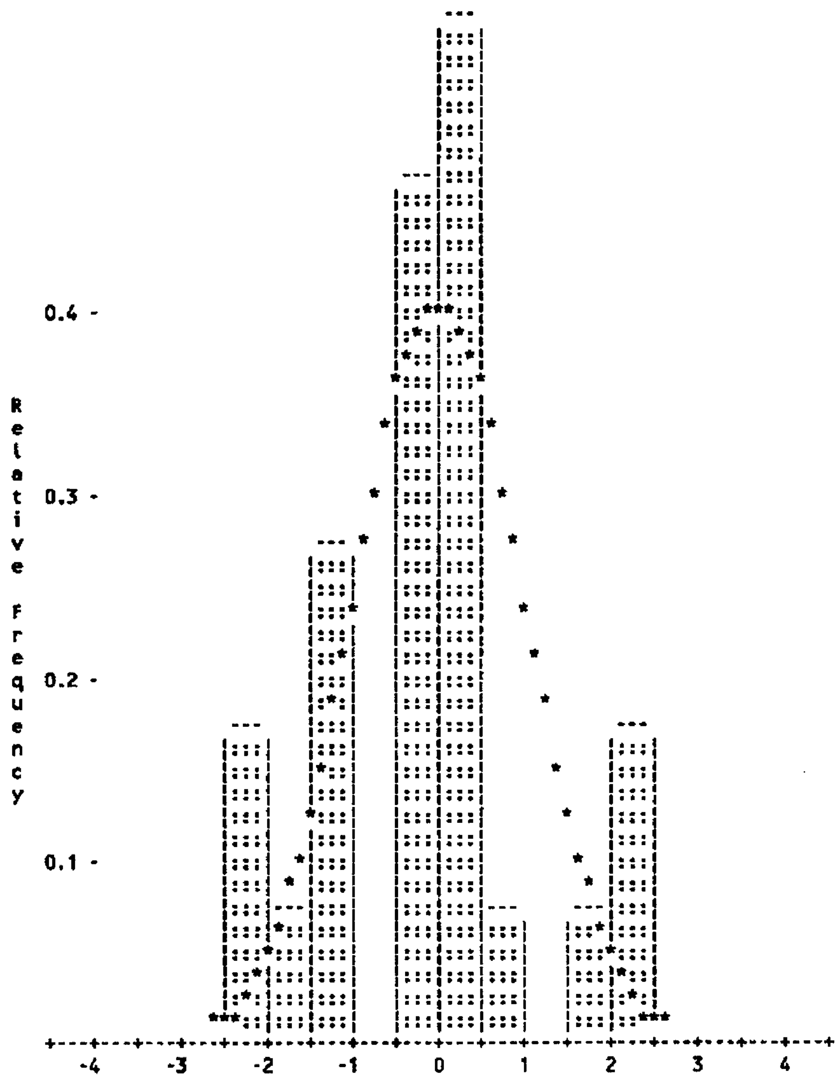
RESID:

STATION	3-D COORD DIFFS	STD.DEV.	RESIDUAL	STD.DEV.	STAN.RES.
	End of Observation Set				
2013	-2709663.6000				
	-4137421.4500				
	4014263.6620				
2001	-2708945.3560	0.0070	0.0003	0.0021	0.1596
	-4142065.2250	0.0200	-0.0005	0.0076	-0.0670
	4010041.3750	0.0150	-0.0004	0.0055	-0.0743
	End of Observation Set				

GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696] Page 11

Figure D-11. (Sheet 4 of 7)

U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
COYOTE DAM   FREE ADJUSTMENT
A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000



Histogram of 3-D Coord Diff (21) Standardized Residuals.

GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]   Page 12

Figure D-11. (Sheet 5 of 7)

U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
COYOTE DAM FREE ADJUSTMENT

A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

S T A T I S T I C S   S U M M A R Y

Residual Critical Value Type	Tau Max
Residual Critical Value	2.5985
Convergence Criterion	0.001000
Final Iteration Counter Value	2
Confidence Level Used	95.0000
Number of Flagged Residuals	0
Estimated Variance Factor	1.3376
Number of Degrees of Freedom	9

Chi-Square Test on the Variance Factor:

6.3283e-001 < 1.0000 < 4.4579e+000 ?

THE TEST PASSES.

RESID successfully completed.

GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696] Page 13

ELLIPSE:

NOTE: All confidence regions were computed using the following factors:

Variance factor used	=	1.33757
Estimated variance factor	=	1.33757
1-D expansion factor	=	1.960
2-D expansion factor	=	2.448
3-D expansion factor	=	2.795

Note that, for relative confidence regions, precisions are computed from the ratio of the major semi-axis and the spatial distance between the two stations.

Error ellipses for which all covariance matrix elements were not computed by INVERT, are marked with an asterisk (*).

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ELLIPSE: 2-D AND 1-D STATION CONFIDENCE REGIONS (95.000 %):

IDENT.	MAJOR SEMI-AXIS	MINOR SEMI-AXIS	AZ(MAJ)	VERTICAL
2001	0.0073	0.0054	124.77	0.0112
2002	0.0074	0.0047	130.94	0.0106
2014	0.0277	0.0211	86.20	0.0483
2013	0.0273	0.0138	95.77	0.0505

GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696] Page 15

Figure D-11. (Sheet 6 of 7)

```
--------------------------------------------------------------------------------
                     U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                            COYOTE DAM      FREE ADJUSTMENT
A=  6378137.000 B=  6356752.314 X0=        0.000 Y0=        0.000 Z0=        0.000
--------------------------------------------------------------------------------


ELLIPSE:        2-D AND 1-D RELATIVE STATION CONFIDENCE REGIONS ( 95.000 %):
-----------------------------------------------------------
FROM     TO        MAJ.SEMI MIN.SEMI AZ(MAJ) VERTICAL SPATIAL DIST.   PRECISION
-------- -------- -------- -------- ------- -------- ------------- ------------
2001     2002        0.0045   0.0038  105.27   0.0082     1165.1856    3.881 PPM
2001     2014        0.0272   0.0204   84.07   0.0475     8095.2706    3.363 PPM
2001     2013        0.0264   0.0125   94.67   0.0494     6317.2966    4.182 PPM
2002     2014        0.0271   0.0203   83.67   0.0473     7000.8237    3.871 PPM
2002     2013        0.0267   0.0130   94.73   0.0499     7404.1516    3.612 PPM
2014     2013        0.0359   0.0216   91.44   0.0607    13490.3592    2.665 PPM
--------------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]       Page     16
--------------------------------------------------------------------------------

ELLIPSE:        3-D STATION CONFIDENCE REGIONS ( 95.000 %):
-------------------------------------------
IDENT.             MAJOR SEMI-AXIS        MEDIUM SEMI-AXIS         MINOR SEMI-AXIS
-------- --------------------- --------------------- ---------------------
2001                    0.0161                  0.0082                  0.0059
                 A=180.0 V= 80.4        A=298.9 V=  4.7        A= 29.6 V=  8.3
2002                    0.0152                  0.0082                  0.0054
                 A=161.8 V= 79.9        A=307.9 V=  8.4        A= 38.7 V=  5.6
2014                    0.0690                  0.0316                  0.0237
                 A=345.0 V= 86.1        A= 85.7 V=  0.7        A=175.8 V=  3.8
2013                    0.0754                  0.0219                  0.0157
                 A= 94.5 V= 72.1        A=279.0 V= 17.9        A=188.6 V=  1.3
--------------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]       Page     17
--------------------------------------------------------------------------------

ELLIPSE:        3-D RELATIVE STATION CONFIDENCE REGIONS ( 95.000 %):
----------------------------------------------------
FROM     TO        MAJOR-SEMI  MED.-SEMI MINOR-SEMI  SPATIAL DIST.     PRECISION
-------- -------- ---------- ---------- ---------- -------------- ------------
2001     2002          0.0117     0.0051     0.0044      1165.1856    10.011 PPM
                  A=  0 V=90 A= 90 V= 0 A=  0 V= 0
2001     2014          0.0679     0.0311     0.0228      8095.2706     8.392 PPM
                  A=347 V=86 A= 84 V= 1 A=174 V= 4
2001     2013          0.0739     0.0201     0.0142      6317.2966    11.704 PPM
                  A= 93 V=72 A=279 V=18 A=188 V= 2
2002     2014          0.0677     0.0309     0.0226      7000.8237     9.666 PPM
                  A=342 V=85 A= 83 V= 1 A=173 V= 4
2002     2013          0.0745     0.0210     0.0148      7404.1516    10.064 PPM
                  A= 93 V=72 A=278 V=18 A=188 V= 1
2014     2013          0.0887     0.0363     0.0245     13490.3592     6.577 PPM
                  A= 85 V=76 A=275 V=14 A=185 V= 2
ELLIPSE successfully completed.
--------------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]       Page     18
```

Figure D-11. (Sheet 7 of 7)

```
                 U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                 COYOTE DAM CONSTRAINED ADJUSTMENT  NAD-83

A= 6378137.000 B= 6356752.314 X0=      0.000 Y0=      0.000 Z0=      0.000
---------------------------------------------------------------------------
PREPARE:     ASCII input file: <coyote_1.iob>.
PREPARE successfully completed.
---------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]    Page    0
---------------------------------------------------------------------------
GETUP:
 -------------------------------------------------------------------------
|           PARAMETERS              |             OBSERVATIONS            |
|-------------------------------------------------------------------------|
|  Description    |    Number       |  Description      |     Number      |
|-------------------------------------------------------------------------|
| All Stations    |          5      | Directions        |          0      |
| Fixed Stations  |          3      | Distances         |          0      |
| Free 3-D Stations|         2      | Azimuths          |          0      |
| Free 2-D Stations|         0      | Vertical Angles   |          0      |
| Free 1-D Stations|         0      | Zenithal Angles   |          0      |
| Coord. Parameters|         6      | Angles            |          0      |
| Astro. Latitudes |         0      | Heights           |          0      |
| Astro. Longitudes|         0      | Height Differences|          0      |
| Geoid Records   |          0      | Auxiliary Params. |          0      |
| All Aux. Pars.  |          4      | 2-D Coords.       |          0      |
| Direction Pars. |          0      | 2-D Coord. Diffs. |          0      |
| Scale Parameters|          1      | 3-D Coords.       |          0      |
| Constant Pars.  |          0      | 3-D Coord. Diffs. |         21      |
| Rotation Pars.  |          3      |                   |                 |
| Translation Pars.|         0      |                   |                 |
|                 |                 |                   |                 |
|                 |   --------      |                   |   --------      |
| Total Parameters|         10      | Total Observations|         21      |
|-------------------------------------------------------------------------|
|                   Degrees of Freedom =      11                          |
 -------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]    Page    1


---------------------------------------------------------------------------
GETUP:                  SUMMARY  OF  SELECTED  OPTIONS
---------------------------------------------------------------------------
     OPTION                          |     SELECTION
-------------------------------------|-------------------------------------
     Computation Mode                |     Adjustment
     Linear Unit                     |     Metre
     Maximum Iterations              |     2
     Confidence Regions Selected     |     All
     Confidence Region Dimensions    |     1-D, 2-D, and 3-D
     Print Input Station Data        |     On
     Variance Factor Knowledge       |     Known
     Confidence Level for Statistics |     95.000
     Dual-Height Mode                |     Off
     Print Solution Vector           |     On All Iterations
     Printed Ellipsoidal Coordinates |     5 Decimal Places
     Print Adjusted X, Y, Z          |     On
     Print Histograms                |     On
     Print Misclosures               |     On All Iterations
     Print Residuals                 |     All
     Variance Factor Usage           |     Scale Confidence Regions
     Residual Rejection Criterion    |     Tau Max
     Angular Misclosure Limit Factor |     10
     Linear Misclosure Limit Factor  |     10
     Convergence Criterion           |     0.001000
---------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]    Page    2
```

Figure D-12. GEOLAB adjustment output (constrained) (Sheet 1 of 7)

```
----------------------------------------------------------------------------
                 U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                       COYOTE DAM ADJUSTMENT  NAD-83
A=  6378137.000 B=  6356752.314 X0=        0.000 Y0=        0.000 Z0=        0.000
----------------------------------------------------------------------------
CODE IDENT.    DESCRIPTOR        INITIAL VALUES
---- ------    ----------        --------------
 14  2006
               ELLIPSOIDAL :   39 11 34.37462 -123 10 10.28988        336.0850
               ASTRONOMIC  :   39 11 34.37462 -123 10 10.28988        336.0850
               GEOIDAL     :    0  0  0.00000    0  0  0.00000          0.0000
               CARTESIAN   :    -2708280.4788     -4143494.7721   4009147.8933

 14  2013
               ELLIPSOIDAL :   39 15 12.11624 -123 13 17.48887        222.8350
               ASTRONOMIC  :   39 15 12.11624 -123 13 17.48887        222.8350
               GEOIDAL     :    0  0  0.00000    0  0  0.00000          0.0000
               CARTESIAN   :    -2709665.3418     -4137409.4525   4014278.4657

 14  2014
               ELLIPSOIDAL :   39  7 57.41258 -123 12 14.77684        190.1700
               ASTRONOMIC  :   39  7 57.41258 -123 12 14.77684        190.1700
               GEOIDAL     :    0  0  0.00000    0  0  0.00000          0.0000
               CARTESIAN   :    -2713032.7742     -4145300.4693   4003867.7960

 24  2001
               ELLIPSOIDAL :   39 12 14.43422 -123 11  6.45941        243.8658
               ASTRONOMIC  :   39 12 14.43422 -123 11  6.45941        243.8658
               GEOIDAL     :    0  0  0.00000    0  0  0.00000          0.0000
               CARTESIAN   :    -2708942.2350     -4142043.8310   4010047.0300

 24  2002
               ELLIPSOIDAL :   39 11 37.00656 -123 11  0.94286        243.8815
               ASTRONOMIC  :   39 11 37.00656 -123 11  0.94286        243.8815
               GEOIDAL     :    0  0  0.00000    0  0  0.00000          0.0000
               CARTESIAN   :    -2709230.7400     -4142726.8330   4009152.5340

 94  WGSXX
               3DD  SCAL   :            0.00000
               3DD  ROTX   :            0.00000
               3DD  ROTY   :            0.00000
               3DD  ROTZ   :            0.00000
GETUP successfully completed.
----------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]      Page     3
FORMEQ:                  NOTE 6: Reordering was done.
AT        TO       OBS TYPE              OBSERVATION  APPROX.SIG.   MISCLOSURE
--------  -------- ---------------- ---------------  -----------  -----------
2001      2006     3-D X-Coord Diff        666.6170       0.0037      -4.8608
2001      2006     3-D Y-Coord Diff      -1441.5480       0.0045      -9.3931
2001      2006     3-D Z-Coord Diff       -908.2800       0.0028       9.1433
2002      2006     3-D X-Coord Diff        953.2950       0.0022      -3.0338
2002      2006     3-D Y-Coord Diff       -748.3180       0.0044     -19.6211
2002      2006     3-D Z-Coord Diff        -16.7100       0.0029      12.0693
2001      2002     3-D X-Coord Diff       -286.6690       0.0024      -1.8360
2001      2002     3-D Y-Coord Diff       -693.2190       0.0026      10.2170
2001      2002     3-D Z-Coord Diff       -891.5890       0.0025      -2.9070
2001      2002     3-D X-Coord Diff       -286.6790       0.0026      -1.8260
2001      2002     3-D Y-Coord Diff       -693.2230       0.0030      10.2210
2001      2002     3-D Z-Coord Diff       -891.5780       0.0026      -2.9180
2014      2002     3-D X-Coord Diff       3799.0050       0.0129       3.0292
2014      2002     3-D Y-Coord Diff       2554.0180       0.0101      19.6183
2014      2002     3-D Z-Coord Diff       5296.7980       0.0113     -12.0600
2013      2001     3-D X-Coord Diff        718.2440       0.0059       4.8628
2013      2001     3-D Y-Coord Diff      -4643.7750       0.0083       9.3965
2013      2001     3-D Z-Coord Diff      -4222.2870       0.0059      -9.1487
FORMEQ successfully completed.
----------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]      Page     4
```

Figure D-12. (Sheet 2 of 7)

```
---------------------------------------------------------------------------
                      U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                            COYOTE DAM ADJUSTMENT  NAD-83
A=  6378137.000 B=  6356752.314 XO=       0.000 YO=        0.000 ZO=        0.000
---------------------------------------------------------------------------
SOLVE:      Solution (Iteration Count = 1):
CODE IDENT.  TYPE                INITIAL            DX               UPDATED
---- -------- --------- ----------------- ------------- -----------------

 24  2001     LATITUDE    39  12  14.43422       0.01413    39  12  14.44836
 24  2001     LONGITUDE -123  11   6.45941       0.04476  -123  11   6.41465
 24  2001     HEIGHT             243.86577      13.93968            257.80545

 24  2002     LATITUDE    39  11  37.00656      -0.06729    39  11  36.93927
 24  2002     LONGITUDE -123  11   0.94286       0.34171  -123  11   0.60115
 24  2002     HEIGHT             243.88154      21.63406            265.51561

 94  WGSXX    3DD SCAL             0.00000      -0.00161             -0.00161
 94  WGSXX    3DD ROTX             0.00000       0.03270              0.03270
 94  WGSXX    3DD ROTY             0.00000      -0.06406             -0.06406
 94  WGSXX    3DD ROTZ             0.00000      -0.04338             -0.04338
SOLVE successfully completed.
---------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]       Page    5
---------------------------------------------------------------------------
FORMEQ:                    FORMEQ successfully completed.
---------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]       Page    6
---------------------------------------------------------------------------
---------------------------------------------------------------------------
SOLVE:            Adjusted Values (Iteration Count = 2):
CODE IDENT.  TYPE                INITIAL            DX              ADJUSTED
---- -------- --------- ----------------- ------------- -----------------

 14  2006     LATITUDE    39  11  34.37462         FIXED
 14  2006     LONGITUDE -123  10  10.28988         FIXED
 14  2006     HEIGHT             336.08500         FIXED

 14  2013     LATITUDE    39  15  12.11624         FIXED
 14  2013     LONGITUDE -123  13  17.48887         FIXED
 14  2013     HEIGHT             222.83500         FIXED

 14  2014     LATITUDE    39   7  57.41258         FIXED
 14  2014     LONGITUDE -123  12  14.77684         FIXED
 14  2014     HEIGHT             190.17000         FIXED

 24  2001     LATITUDE    39  12  14.44836       0.00000    39  12  14.44836
 24  2001     LONGITUDE -123  11   6.41465       0.00000  -123  11   6.41465
 24  2001     HEIGHT             257.80545      -0.00000            257.80545

 24  2002     LATITUDE    39  11  36.93927       0.00000    39  11  36.93927
 24  2002     LONGITUDE -123  11   0.60115      -0.00000  -123  11   0.60115
 24  2002     HEIGHT             265.51561       0.00000            265.51561

 94  WGSXX    3DD SCAL            -0.00161       0.00000             -0.00161
 94  WGSXX    3DD ROTX             0.03270      -0.00000              0.03270
 94  WGSXX    3DD ROTY            -0.06406       0.00000             -0.06406
 94  WGSXX    3DD ROTZ            -0.04338       0.00000             -0.04338

---------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]       Page    7
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Figure D-12. (Sheet 3 of 7)

```
                     U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                          COYOTE DAM ADJUSTMENT  NAD-83
A=  6378137.000 B=  6356752.314 X0=        0.000 Y0=        0.000 Z0=        0.000
-----------------------------------------------------------------------------------
                          Adjusted Cartesian Coordinates:

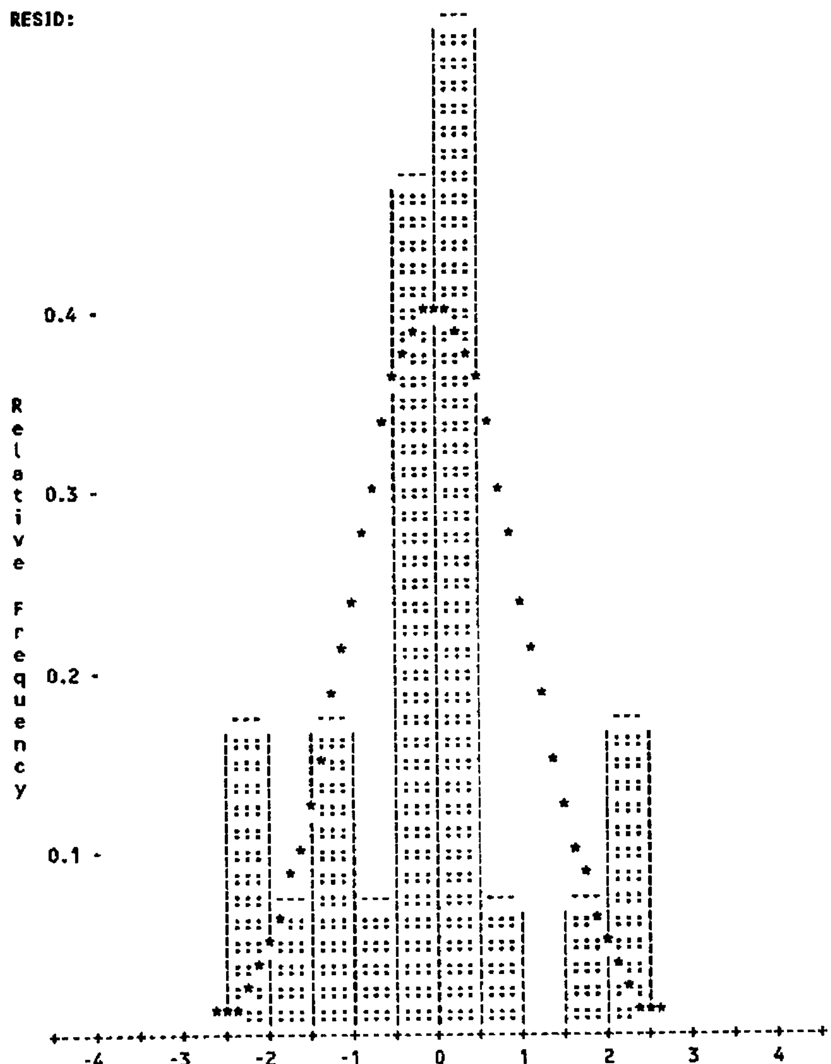
CODE IDENT.          X-COORDINATE       Y-COORDINATE        Z-COORDINATE
---- --------    ----------------   ----------------    ----------------
 24  2001           -2708947.0978      -4142053.2284        4010056.1788
 24  2002           -2709233.7715      -4142746.4512        4009164.5972
SOLVE successfully completed.
-----------------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]       Page      8
-----------------------------------------------------------------------------------
INVERT:          INVERT successfully completed.
-----------------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]       Page      9
-----------------------------------------------------------------------------------
RESID:

STATION    3-D COORD DIFFS    STD.DEV.    RESIDUAL    STD.DEV.   STAN.RES.
--------   ---------------  ----------  ----------  ----------  ----------
2001         -2708942.2350
             -4142043.8310
              4010047.0300
2006         -2708275.6180     0.0050      0.0020      0.0041      0.4865
             -4143485.3790     0.0060      0.0043      0.0045      0.9530
              4009138.7500     0.0040     -0.0055      0.0026     -2.1060
========================= End of Observation Set =========================
2002         -2709230.7400
             -4142726.8330
              4009152.5340
2006         -2708277.4450     0.0030     -0.0024      0.0016     -1.5309
             -4143475.1510     0.0050     -0.0031      0.0032     -0.9650
              4009135.8240     0.0040      0.0063      0.0026      2.3907
========================= End of Observation Set =========================
2001         -2708941.0950
             -4142050.6320
              4010040.8370
2002         -2709227.7640     0.0030     -0.0046      0.0020     -2.2625
             -4142743.8510     0.0040     -0.0036      0.0031     -1.1706
              4009149.2480     0.0040      0.0072      0.0032      2.2786
========================= End of Observation Set =========================
2001         -2708946.1080
             -4142048.2180
              4010039.9500
2002         -2709232.7870     0.0040      0.0054      0.0033      1.6090
             -4142741.4410     0.0040      0.0004      0.0031      0.1285
              4009148.3720     0.0040     -0.0038      0.0032     -1.1993
========================= End of Observation Set =========================
2014         -2713050.5170
             -4145286.8310
              4003867.5850
2002         -2709251.5120     0.0180     -0.0035      0.0149     -0.2328
             -4142732.8130     0.0160     -0.0015      0.0090     -0.1659
              4009164.3830     0.0200      0.0047      0.0141      0.3373
========================= End of Observation Set =========================
2013         -2709663.6000
             -4137421.4500
              4014263.6620
2014         -2713031.0290     0.0150     -0.0018      0.0105     -0.1739
             -4145312.4700     0.0460      0.0055      0.0419      0.1303
              4003852.9890     0.0330      0.0010      0.0293      0.0344

-----------------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]       Page     10
```

Figure D-12. (Sheet 4 of 7)

```
                         U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                              COYOTE DAM ADJUSTMENT  NAD-83
A=  6378137.000 B=  6356752.314 X0=        0.000 Y0=        0.000 Z0=        0.000
--------------------------------------------------------------------------------
STATION     3-D COORD DIFFS     STD.DEV.     RESIDUAL     STD.DEV.    STAN.RES.
--------    ---------------    ----------   ----------   ----------   ----------
========================== End of Observation Set ==========================
2013         -2709663.6000
             -4137421.4500
              4014263.6620
2001         -2708945.3560      0.0070        0.0003      0.0026       0.1237
             -4142065.2250      0.0200       -0.0004      0.0137      -0.0312
              4010041.3750      0.0150       -0.0005      0.0083      -0.0555
========================== End of Observation Set ==========================
--------------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]       Page    11
--------------------------------------------------------------------------------
RESID:
```



Histogram of 3-D Coord Diff (21) Standardized Residuals.

```
--------------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]       Page    12
```

Figure D-12. (Sheet 5 of 7)

```
---------------------------------------------------------------------------
              U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                    COYOTE DAM ADJUSTMENT  NAD-83
A=  6378137.000 B=  6356752.314 X0=      0.000 Y0=      0.000 Z0=      0.000
---------------------------------------------------------------------------
RESID:
 --------------------------------------------------------------------------
|                                                                          |
|                  S T A T I S T I C S    S U M M A R Y                    |
|                                                                          |
|--------------------------------------------------------------------------|
|                                      |                                   |
|     Residual Critical Value Type     |                 Tau Max           |
|     Residual Critical Value          |                  2.7083           |
|     Convergence Criterion            |                0.001000           |
|     Final Iteration Counter Value    |                       2           |
|     Confidence Level Used            |                 95.0000           |
|     Number of Flagged Residuals      |                       0           |
|     Estimated Variance Factor        |                  1.0944           |
|     Number of Degrees of Freedom     |                      11           |
|                                      |                                   |
|--------------------------------------------------------------------------|
|                                                                          |
|               Chi-Square Test on the Variance Factor:                    |
|                                                                          |
|               5.4919e-001  <  1.0000  <  3.1549e+000  ?                  |
|                                                                          |
|                          THE TEST PASSES.                                |
|                                                                          |
 --------------------------------------------------------------------------
RESID successfully completed.
---------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]     Page    13


---------------------------------------------------------------------------
ELLIPSE:
 --------------------------------------------------------------------------
|                                                                          |
| NOTE:  All confidence regions were computed using the following factors: |
|        ----------------------------------------------------------------  |
|        Variance factor used      =        1.09438                        |
|                                                                          |
|        Estimated variance factor =        1.09438                        |
|                                                                          |
|        1-D expansion factor      =          1.960                        |
|                                                                          |
|        2-D expansion factor      =          2.448                        |
|                                                                          |
|        3-D expansion factor      =          2.795                        |
|                                                                          |
|                                                                          |
|        Note that, for relative confidence regions, precisions are        |
|        computed from the ratio of the major semi-axis and the spatial    |
|        distance between the two stations.                               |
|                                                                          |
|        Error ellipses for which all covariance matrix elements           |
|        were not computed by INVERT, are marked with an asterisk (*).     |
|                                                                          |
 --------------------------------------------------------------------------
---------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]     Page    14
```

Figure D-12. (Sheet 6 of 7)

```
U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
COYOTE DAM ADJUSTMENT  NAD-83
A=  6378137.000 B=  6356752.314 XO=        0.000 YO=        0.000 ZO=        0.000
--------------------------------------------------------------------------------
ELLIPSE:                AUXILIARY PARAMETER CONFIDENCE INTERVALS ( 95.000 %):
--------------------------------------------------
IDENT.    TYPE      CLASS           ADJ VALUE      1.96 SIGMA
-------- --------- -------- -------------- ------------
WGSXX     3DD       SCAL            -0.0016          1.1261
                    ROTX       0  0   0.03    0  0   0.82
                    ROTY       0  0  -0.06    0  0   1.27
                    ROTZ       0  0  -0.04    0  0   1.37
--------------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]      Page     15
--------------------------------------------------------------------------------


ELLIPSE:        2-D AND 1-D STATION CONFIDENCE REGIONS ( 95.000 %):
--------------------------------------------------
IDENT.    MAJOR SEMI-AXIS  MINOR SEMI-AXIS  AZ(MAJ)        VERTICAL
-------- ---------------- --------------- -------- ---------------
2001              0.0066           0.0048   107.22           0.0133
2002              0.0062           0.0044   125.62           0.0127
--------------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]      Page     16
--------------------------------------------------------------------------------


ELLIPSE:        2-D AND 1-D RELATIVE STATION CONFIDENCE REGIONS ( 95.000 %):
--------------------------------------------------
FROM      TO        MAJ.SEMI MIN.SEMI AZ(MAJ) VERTICAL SPATIAL DIST.   PRECISION
-------- -------- -------- -------- ------- -------- ------------- -----------
2001      2002       0.0045   0.0036  108.07   0.0082     1165.1856   3.846 PPM
--------------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]      Page     17
--------------------------------------------------------------------------------


ELLIPSE:        3-D STATION CONFIDENCE REGIONS ( 95.000 %):
--------------------------------------------------
IDENT.          MAJOR SEMI-AXIS       MEDIUM SEMI-AXIS        MINOR SEMI-AXIS
-------- -------------------- -------------------- --------------------
2001                   0.0191                0.0070                 0.0056
              A=106.6 V= 81.9       A=270.0 V=  7.8       A=  0.3 V=  2.3
2002                   0.0182                0.0070                 0.0051
              A= 90.0 V= 87.6       A=306.2 V=  1.9       A=216.2 V=  1.4
--------------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]      Page     18
--------------------------------------------------------------------------------


ELLIPSE:        3-D RELATIVE STATION CONFIDENCE REGIONS ( 95.000 %):
--------------------------------------------------
FROM      TO        MAJOR-SEMI  MED.-SEMI MINOR-SEMI  SPATIAL DIST.    PRECISION
-------- -------- ---------- ---------- ---------- ------------- ------------
2001      2002         0.0117     0.0050     0.0042     1165.1856   10.027 PPM
                   A=  0 V=90 A= 90 V= 0 A=  0 V= 0
ELLIPSE successfully completed.
--------------------------------------------------------------------------------
GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]      Page     19
```

Figure D-12. (Sheet 7 of 7)

(1:10,000). The relative line accuracy between 2001 and 2002 on the constrained adjustment was 3.846 ppm, or 1:260,000. This indicates excellent connections with existing control.

d. The variance factor shown on page 14 of each adjustment is within acceptable limits (0.5 to 1.5). As such, it could be used to determine outlier limits for rejection of data, as explained in Chapter 11.

e. The residual corrections to each baseline component are shown on page 10 of each adjustment. Special review is made of the standardized residuals, which one will find is approximately comparable to normalized residuals in GEOLAB software. None of the residuals were flagged (based on Tau Max testing) for exceeding tolerance.

f. The 3D positional and relative confidence regions (ellipsoid) and 3D line accuracy precessions are shown at the end of each adjustment. These statistics are not applicable for most USACE work.

g. Of all the output statistics, only the residuals, standardized residuals, relative 2D/1D line precessions, and variance factor have useful application for USACE work. The histograms, Chi-square tests, 3D ellipsoid, etc. are useful only if one understands their derivation and application.

h. The results of the free and constrained adjustments in this example were not significantly different. This is usually not the case -- typically, station/line accuracies degrade on the constrained adjustment.

Section II
Survey No. 2: Precise Control Survey
(Dworshak Dam, Idaho)

D-7. General

A high precision GPS control survey may be performed at sites for structural deformation monitoring. Accurate control in the vicinity of the structure is critical. Absolute NGRS coordinate on monitoring points is of lesser importance. NGRS control may be brought into one of the reference points with GPS. Only the NGRS coordinates of this fixed point are held fixed for all subsequent adjustments in the vicinity of the structure.

D-8. Project Description

Survey example No. 2 was conducted in the vicinity of Dworshak Dam, Idaho. A diagram of the project is shown in Figure D-13. Baseline data from the NGRS control to one point (Fish Hatchery - 4001) at the project site were collected and other baseline data for baselines between 4001, Big Eddy (4002), and four points on the Dworshak Dam and Reservoir (4003, 4004, 4005, and 4006) as shown in Figure D-14. Loop closure checks were done for the complete network by using the loop closure routine shown in Figure D-15. The resultant precision for the loop is 0.43 ppm (1:2,300,000).

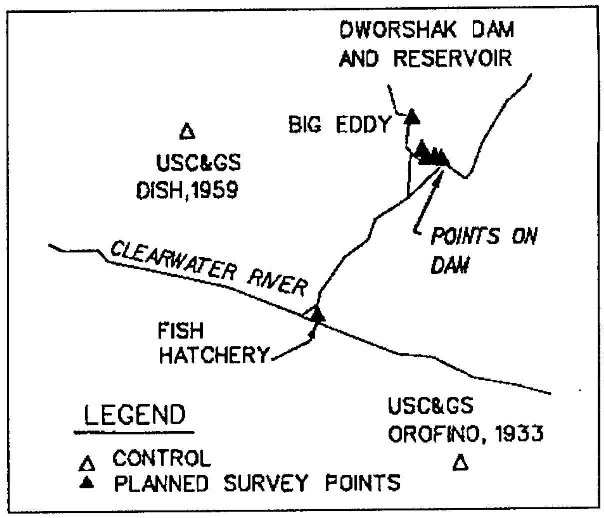


Figure D-13. Dworshak Dam and Project area

D-9. Adjustment

a. An IOB file for the adjustment based on the formulated baselines was set up. Station USC&GS Dish, 1959, and USC&GS Orofino, 1933, were held fixed to establish NGRS control on Corps of Engineers Station 4001 at the project site. Then, for the next adjustment, 4001 was held fixed to adjust station 4002, 4003, 4004, 4005, and 4006. This free adjustment is shown in Figure D-16. Analysis of the adjustment was done as in Survey No. 1 and detailed in Chapter 11.

b. The resultant adjustment statistics are shown on page 14 of Figure D-16. The 2D station confidence is on the order of 0.04 m (2DRMS) and $\pm$0.06 m in the vertical. The largest line accuracy is 36.322 ppm (1:27,000)

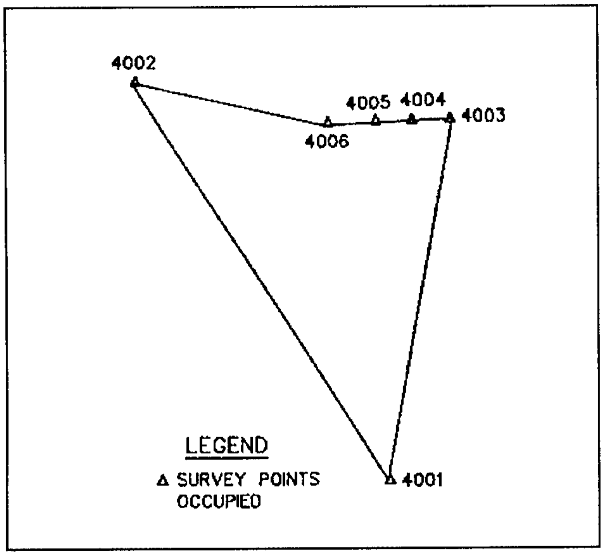


Figure D-14. GPS project diagram (Dworshak)

over a short (62 m) baseline. This would be acceptable even though a 1:100,00 relative accuracy is required. Due to fixed centering errors, maintaining 1:100,000 relative accuracies over lines less than 200 to 500 m is unrealistic.

Section III
Survey No. 3: Upper Saginaw River Control Project. (Saginaw, Michigan).

D-10. Planning Phase

a. The GPS survey was planned for 24-25 March 1993, Julian day 083 and 084 in the vicinity of Saginaw, Michigan.

b. This project was to establish Second-Order control, using GPS, at the Upper Saginaw River. The project area covered from Green Point down to the railroad bridge of the upper end of the condition survey project area, see Figure D-17. These control stations were to

```
Trimble Loop Closure Utility

Start Traverse at Station:  4006
Starting Coords :  46x30'56.88832"ØN   116x17'48.33684"ØW          489.943

Baseline 1
File Name: 06053001.FIX
From Station:  4006                        To Station:  4005
Distance Travelled (m):          62.829
Current Coords  :  46x30'55.20552"ØN   116x17'46.75486"ØW          500.412

Baseline 2
File Name: 05042993.FIX
From Station:  4005                        To Station:  4004
Distance Travelled (m):         124.262
Current Coords  :  46x30'54.30015"ØN   116x17'44.23756"ØW          489.809

Baseline 3
File Name: 04032891.FIX
From Station:  4004                        To Station:  4003
Distance Travelled (m):         214.384
Current Coords  :  46x30'51.68841"ØN   116x17'42.38493"ØW          497.376

Baseline 4
File Name: 01032992.FIX
From Station:  4003                        To Station:  4001
Distance Travelled (m):        2872.755
Current Coords  :  46x30'05.98881"ØN   116x19'27.67811"ØW          308.887

Baseline 5
File Name: 01023012.FIX
From Station:  4001                        To Station:  4002
Distance Travelled (m):        6122.940
Current Coords  :  46x31'41.46032"ØN   116x18'24.06337"ØW          490.036

Baseline 6
File Name: 02063001.FIX
From Station:  4002                        To Station:  4006
Distance Travelled (m):        7695.981
Current Coords  :  46x30'56.88826"ØN   116x17'48.33690"ØW          489.941

End Traverse at Station:  4006
Distance Travelled (m):          7695.981    Precision (ppm):        0.43
dx:     -0.001      dy:      0.001      dz:     -0.003      dh:     -0.002
Ending Coords    :  46x30'56.88826"ØN   116x17'48.33690"ØW          489.941
Reference Coords :  46x30'56.88832"ØN   116x17'48.33684"ØW          489.943
```

Figure D-15. Loop closure (Dworshak)

```
U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=  0.000 Y0=  0.000 Z0=  0.000

PREPARE:

ASCII input file: <wal_1.iob>.

PREPARE successfully completed.

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```

```
U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=  0.000 Y0=  0.000 Z0=  0.000

GETUP:
```

PARAMETERS		OBSERVATIONS	
Description	Number	Description	Number
All Stations	6	Directions	0
Fixed Stations	1	Distances	0
Free 3-D Stations	5	Azimuths	0
Free 2-D Stations	0	Vertical Angles	0
Free 1-D Stations	0	Zenithal Angles	0
Coord. Parameters	15	Angles	0
Astro. Latitudes	0	Heights	0
Astro. Longitudes	0	Height Difference	0
Geoid Records	0	Auxiliary Params.	0
All Aux. Pars.	0	2-D Coords.	0
Direction Pars.	0	2-D Coord. Diffs.	0
Scale Parameters	0	3-D Coords.	0
Constant Pars.	0	3-D Coord. Diffs.	60
Rotation Pars.	0		
Translation Pars.	0		
	-----		-----
Total Parameters	15	Total Observations	60
Degrees of Freedom = 45			

```
GeoLab-V1.82S,(C)1985/86/87BitWise Ideas Inc.[103207687] Page  1
```

Figure D-16. GEOLAB adjustment output (Sheet 1 of 8)

```
U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=   0.000 Y0=   0.000 Z0=   0.000
```

GETUP

SUMMARY OF SELECTED OPTIONS

OPTION	SELECTION
Computation Mode	Adjustment
Linear Unit	Metre
Maximum Iterations	2
Confidence Regions Selected	All
Confidence Region Dimensions	1-D and 2-D only
Print Input Station Data	Off
Variance Factor Knowledge	Known
Confidence Level for Statistics	95.000
Dual-Height Mode	Off
Print Solution Mode	Only Adjusted Values
Printed Ellipsoidal Coordinates	5 Decimal Places
Print Adjusted X, Y, Z	On
Print Histograms	On
Print Misclosures	On
Print Residuals	On All Iterations
Variance Factor Usage	Scale Confidence Regions
Residual Rejection Criterion	Tau Max
Angular Misclosure Limit Factor	10
Linear Misclosure Limit Factor	10
Convergence Criterion	0.001000

SETUP successfully completed.

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Figure D-16. (Sheet 2 of 8)

U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
DWORSHAK DAM

A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

FORMEQ:

NOTE 6: Reordering was done.

AT	TO	OBS TYPE	OBSERVATION	APPROX.SIG.	MISCLOSURE
4001	4003	3-D X-Coord Diff	2408.6880	0.0029	22.8708
4001	4003	3-D Y-Coord Diff	-193.5840	0.0016	25.8258
4001	4003	3-D Z-Coord Diff	1108.0180	0.0021	-26.6407
4004	4003	3-D X-Coord Diff	7.1790	0.0007	22.7040
4004	4003	3-D Y-Coord Diff	-74.6270	0.0003	21.7690
4004	4003	3-D Z-Coord Diff	-50.0120	0.0006	-25.7900
4001	4004	3-D X-Coord Diff	2401.5070	0.0055	.1688
4001	4004	3-D Y-Coord Diff	-118.9530	0.0065	4.0528
4001	4004	3-D Z-Coord Diff	1158.0230	0.0062	-0.8437
4001	4002	3-D X-Coord Diff	2108.6340	0.0061	-1.6862
4001	4002	3-D Y-Coord Diff	1204.4260	0.0079	36.7548
4001	4002	3-D Z-Coord Diff	2160.2690	0.0067	-27.6797
4001	4003	3-D X-Coord Diff	2408.6870	0.0055	22.8718
4001	4003	3-D Y-Coord Diff	-193.5780	0.0072	25.8198
4001	4003	3-D Z-Coord Diff	1108.0110	0.0062	-26.6337
4001	4005	3-D X-Coord Diff	2359.1380	0.0047	-0.9472
4001	4005	3-D Y-Coord Diff	-83.5390	0.0122	5.9208
4001	4005	3-D Z-Coord Diff	1184.9630	0.0073	-7.2267
4005	4004	3-D X-Coord Diff	42.3580	0.0008	1.1270
4005	4004	3-D Y-Coord Diff	-35.4190	0.0015	-1.8630
4005	4004	3-D Z-Coord Diff	-26.9330	0.0006	6.3760
4001	4002	3-D X-Coord Diff	2108.6240	0.0045	-1.6762
4001	4002	3-D Y-Coord Diff	1204.4190	0.0104	36.7618
4001	4002	3-D Z-Coord Diff	2160.2710	0.0063	-27.6817
4001	4006	3-D X-Coord Diff	2348.8140	0.0033	32.4128
4001	4006	3-D Y-Coord Diff	-28.3330	0.0019	24.3928
4001	4006	3-D Z-Coord Diff	1213.1260	0.0021	-23.8437
4006	4005	3-D X-Coord Diff	10.3400	0.0008	-33.3760
4006	4005	3-D Y-Coord Diff	-55.2020	0.0004	-18.4760
4006	4005	3-D Z-Coord Diff	-28.1650	0.0007	16.6190
4002	4006	3-D X-Coord Diff	240.1770	0.0031	34.1020
4002	4006	3-D Y-Coord Diff	-1232.7570	0.0020	-12.3640
4002	4006	3-D Z-Coord Diff	-947.1440	0.0019	3.8370
4002	4005	3-D X-Coord Diff	250.5120	0.0027	0.7310
4002	4005	3-D Y-Coord Diff	-1287.9560	0.0040	-30.8430
4002	4005	3-D Z-Coord Diff	-975.3050	0.0031	20.4520
4001	4005	3-D X-Coord Diff	2359.1440	0.0055	-0.9532
4001	4005	3-D Y-Coord Diff	-83.5400	0.0067	5.9218
4001	4005	3-D Z-Coord Diff	1184.9690	0.0063	-7.2327
4001	4006	3-D X-Coord Diff	2348.8070	0.0054	32.4198
4001	4006	3-D Y-Coord Diff	-28.3370	0.0066	24.3968
4001	4006	3-D Z-Coord Diff	1213.1310	0.0062	-23.8487
4002	4003	3-D X-Coord Diff	300.0520	0.0022	24.5590
4002	4003	3-D Y-Coord Diff	-1398.0030	0.0043	-10.9360

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Figure D-16. (Sheet 3 of 8)

```
-----------------------------------------------------------------------
              U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                              DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=   0.000 Y0=   0.000 Z0=   0.000
-----------------------------------------------------------------------
FORMEQ:
AT     TO     OBS TYPE              OBSERVATION  APPROX.SIG. MISCLOSURE
-----  -----  ------------------  ------------  -----------  -----------
4002   4003   3-D X-Coord Diff     -1052.2550        0.0024      1.0430
4006   4003   3-D X-Coord Diff        59.8780        0.0007     -9.5460
4006   4003   3-D Y-Coord Diff      -165.2500        0.0015      1.4320
4006   4003   3-D Z-Coord Diff      -165.2500        0.0006     -2.7900
4001   4002   3-D X-Coord Diff      2108.6250        0.0045     -1.6772
4001   4002   3-D Y-Coord Diff      1204.4170        0.0104     36.7638
4001   4002   3-D Z-Coord Diff      2160.2740        0.0063    -27.6847
4001   4002   3-D X-Coord Diff      2108.6270        0.0043     -1.6792
4001   4002   3-D Y-Coord Diff      1204.4160        0.0028     36.7648
4001   4002   3-D Z-Coord Diff      2160.2680        0.0029    -27.6787
4001   4002   3-D X-Coord Diff      2108.6320        0.0063     -1.6842
4001   4002   3-D Y-Coord Diff      1204.4280        0.0078     36.7528
4001   4002   3-D Z-Coord Diff      2160.2620        0.0062    -27.6727
4001   4002   3-D X-Coord Diff      2108.6250        0.0045     -1.6772
4001   4002   3-D Y-Coord Diff      1204.4170        0.0101     36.7638
4001   4002   3-D Z-Coord Diff      2160.2780        0.0061    -26.6887

FORMEQ successfully completed.
-----------------------------------------------------------------------
GeoLab-V1.82S,(C)1985/86/87BitWise Ideas Inc.[103207687] Page   4
```

```
-----------------------------------------------------------------------
              U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                              DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=   0.000 Y0=   0.000 Z0=   0.000
-----------------------------------------------------------------------
SOLVE:
SOLVE successfully completed.

-----------------------------------------------------------------------
GeoLab-V1.82S,(C)1985/86/87BitWise Ideas Inc.[103207687] Page   5
```

```
-----------------------------------------------------------------------
              U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                              DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=   0.000 Y0=   0.000 Z0=   0.000
-----------------------------------------------------------------------
FORMEQ:
FORMEQ successfully completed.

-----------------------------------------------------------------------
GeoLab-V1.82S,(C)1985/86/87BitWise Ideas Inc.[103207687] Page   6
```

Figure D-16. (Sheet 4 of 8)

```
                U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                              DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=  0.000 Y0=  0.000 Z0=   0.000
-----------------------------------------------------------------
SOLVE:

Adjusted Values (Iteration Count = 2):

CODE IDENT. TYPE                  INITIAL        DX         ADJUSTED
---- ------ --------- ----------------- -------- ----------------
 14  4001   LATITUDE     46  30  5.78733   FIXED
 14  2006   LONGITUDE  -116  19 17.36405   FIXED
 14  2006   HEIGHT              312.18200   FIXED

 24  4003   LATITUDE     46  30 51.48677  0.00000  46   30 51.48677
 24  4003   LONGITUDE  -116  17 42.07099  0.00000 -116 17 42.07099
 24  4003   HEIGHT              500.68216  0.00001        500.68217

 24  4004   LATITUDE     46  30 54.09853  0.00000  46   30 54.09853
 24  4004   LONGITUDE  -116  17 43.92366 -0.00000 -116 17 43.92366
 24  4004   HEIGHT              493.11850  0.00000        493.11851

 24  4002   LATITUDE     46  30 41.25876  0.00000  46 31  41.25876
 24  4002   LONGITUDE  -116  18 23.74916 -0.00001 -116 18 23.74917
 24  4002   HEIGHT              493.34210  0.00003        493.34213

 24  4005   LATITUDE     46  30 55.00394 -0.00000  46 30  36.93927
 24  4005   LONGITUDE  -116  17 46.44097 -0.00000 -116 17 46.44097
 24  4005   HEIGHT              503.72111  0.00000        503.72111

 24  4006   LATITUDE     46  30 56.68676  0.00000 46 30  56.68676
 24  4006   LONGITUDE  -116  17 48.02294  0.00001 -116 17 48.02294
 24  4006   HEIGHT              493.25364  0.00003        493.25367
-----------------------------------------------------------------
GeoLab-V1.82S,(C)1985/86/87BitWise Ideas Inc.[103207687] Page  7
-----------------------------------------------------------------
                U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                              DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=  0.000 Y0=  0.000 Z0=   0.000
-----------------------------------------------------------------
Adjusted Cartesian Coordinates:

CODE IDENT.      X-COORDINATE     Y-COORDINATE      Z-COORDINATE
---- ------ ---------------- ---------------- ---------------
 24  4003      -1948002.5548    -3942346.3361     4605137.8787
 24  4004      -1948009.7358    -3942271.7102     4605187.8935
 24  4002      -1948302.6080    -3940948.3316     4606190.1331
 24  4005      -1948052.0934    -3942236.2903     4605213.8271
 24  4006      -1948062.4335    -3942181.0887     4605242.9935

SOLVE successfully completed.

-----------------------------------------------------------------
GeoLab-V1.82S,(C)1985/86/87BitWise Ideas Inc.[103207687] Page  8
-----------------------------------------------------------------
                U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                              DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=  0.000 Y0=  0.000 Z0=   0.000
-----------------------------------------------------------------
INVERT:

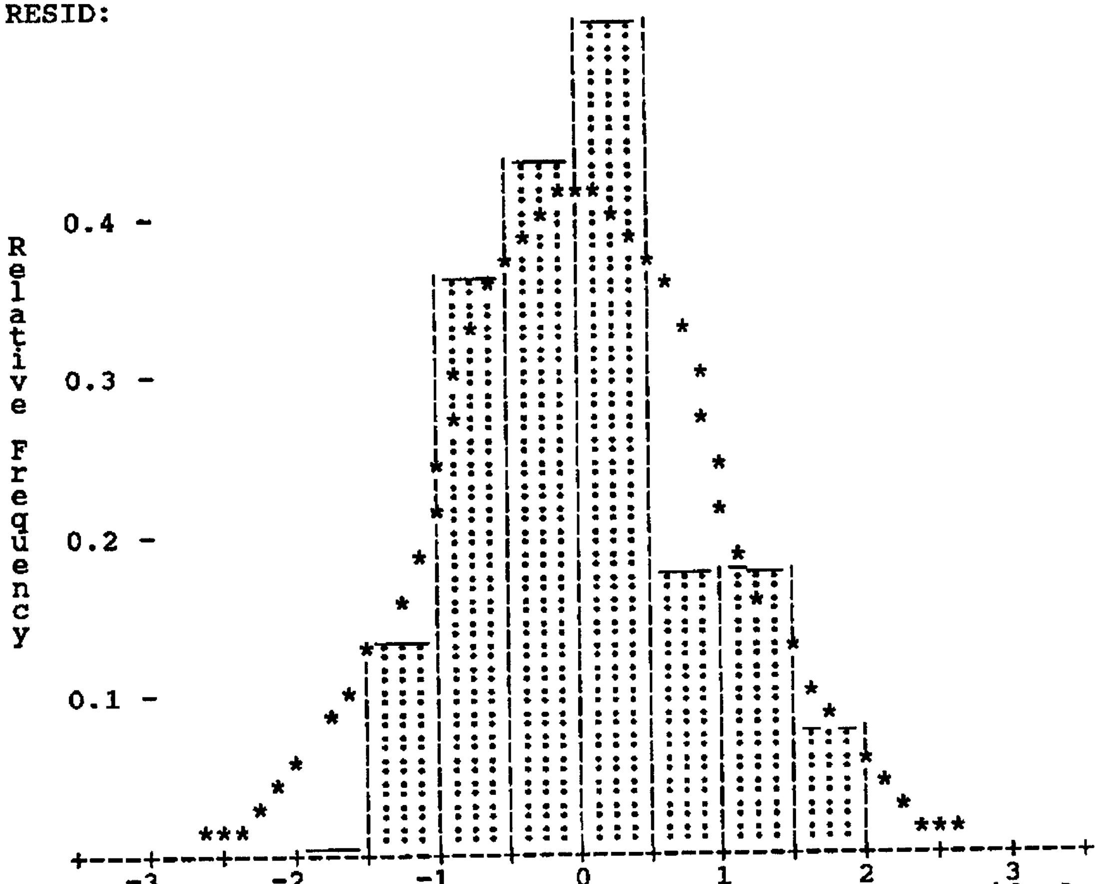
INVERT successfully completed.

-----------------------------------------------------------------
GeoLab-V1.82S,(C)1985/86/87BitWise Ideas Inc.[103207687] Page  9
```

Figure D-16. (Sheet 5 of 8)

U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
DWORSHAK DAM
A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

RESID:



Histrogram of 3-D Coord Diff (21) Standardized Residuals.

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Figure D-16. (Sheet 6 of 8)

```
                U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                               DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=  0.000 Y0=  0.000 Z0=  0.000
-----------------------------------------------------------------
RESID:

 ---------------------------------------------------------------
|                                                               |
|          S T A T I S T I C S   S U M M A R Y                  |
|                                                               |
|---------------------------------------------------------------|
|                                       |                       |
|  Residual Critical Value Type         |          Tau Max      |
|  Residual Critical Value              |           3.3469      |
|  Convergence Criterion                |         0.001000      |
|  Final Iteration Counter Value        |                2      |
|  Confidence Level Used                |          95.0000      |
|  Number of Flagged Residuals          |                0      |
|  Estimated Variance Factor            |           0.8676      |
|  Number of Degrees of Freedom         |               45      |
|                                       |                       |
|---------------------------------------------------------------|
|                                                               |
|          Chi-Square Test on the Variance Factor:              |
|                                                               |
|          5.9685e-001  <  1.0000  <  1.3763e+000  ?            |
|                                                               |
|                     THE TEST PASSES.                          |
|                                                               |
 ---------------------------------------------------------------

RESID successfully completed.
-----------------------------------------------------------------
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-----------------------------------------------------------------
                U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                               DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=  0.000 Y0=  0.000 Z0=  0.000
-----------------------------------------------------------------
ELLIPSE:

 ---------------------------------------------------------------
|                                                               |
|  NOTE:  All confidence regions were                           |
|                computed using the following factors:          |
|    -------------------------------------------------------    |
|        Variance factor used          =     0.86755            |
|                                                               |
|        Estimated variance factor     =     0.86755            |
|                                                               |
|        1-D expansion factor          =       1.960            |
|                                                               |
|        2-D expansion factor          =       2.448            |
|                                                               |
|        3-D expansion factor          =       2.795            |
|                                                               |
|    Note that, for relative confidence regions, precisions     |
|    are computed from the ration of the major semi-axis        |
|    and the spatial distance between the two stations.         |
|                                                               |
|    Error ellipses for which all covariance matrix elements    |
|    were not computed by INVERT, are marked with an asterick(*)|
|                                                               |
 ---------------------------------------------------------------
-----------------------------------------------------------------
GeoLab-V1.82S,(C)1985/86/87BitWise Ideas Inc.[103207687] Page 12
```

Figure D-16. (Sheet 7 of 8)

U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
DWORSHAK DAM
A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

ELLIPSE:

2-D AND 1-D STATION CONFIDENCE REGIONS (95.000 %):

IDENT.	MAJOR SEMI-AXIS	MINOR SEMI-AXIS	AZ(MAJ)	VERTICAL
4003	0.0034	0.0022	76.62	0.0056
4004	0.0036	0.0023	82.71	0.0057
4002	0.0035	0.0026	89.02	0.0061
4005	0.0035	0.0023	82.89	0.0057
4006	0.0035	0.0022	79.03	0.0056

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U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
DWORSHAK DAM
A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

ELLIPSE:

2-D and 1-D RELATIVE STATION CONFIDENCE REGIONS (95.000 %):

FROM	TO	MAJ.SEMI	MIN.SEMI	AZ(MAJ)	VERT.	SPAT.DIST.	PREC.
4003	4004	0.0023	0.0008	89.79	0.0033	90.1225	25.220PPM
4003	4002	0.0033	0.0026	96.46	0.0057	1775.2993	1.847PPM
4003	4005	0.0025	0.0016	104.89	0.0038	143.1265	17.408PPM
4003	4006	0.0018	0.0014	130.30	0.0027	204.7957	8.998PPM
4004	4002	0.0035	0.0027	97.42	0.0059	1685.7014	2.064PPM
4004	4005	0.0019	0.0014	128.56	0.0027	61.4342	30.745PPM
4004	4006	0.0026	0.0016	102.27	0.0039	118.4286	21.633PPM
4002	4005	0.0033	0.0025	92.33	0.0056	1634.8752	2.019PPM
4002	4006	0.0033	0.0024	85.85	0.0056	1573.0376	2.098PPM
4005	4006	0.0023	0.0009	88.94	0.0033	62.8290	36.322PPM

ELLIPSE successfully completed.

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Figure D-16. (Sheet 8 of 8)

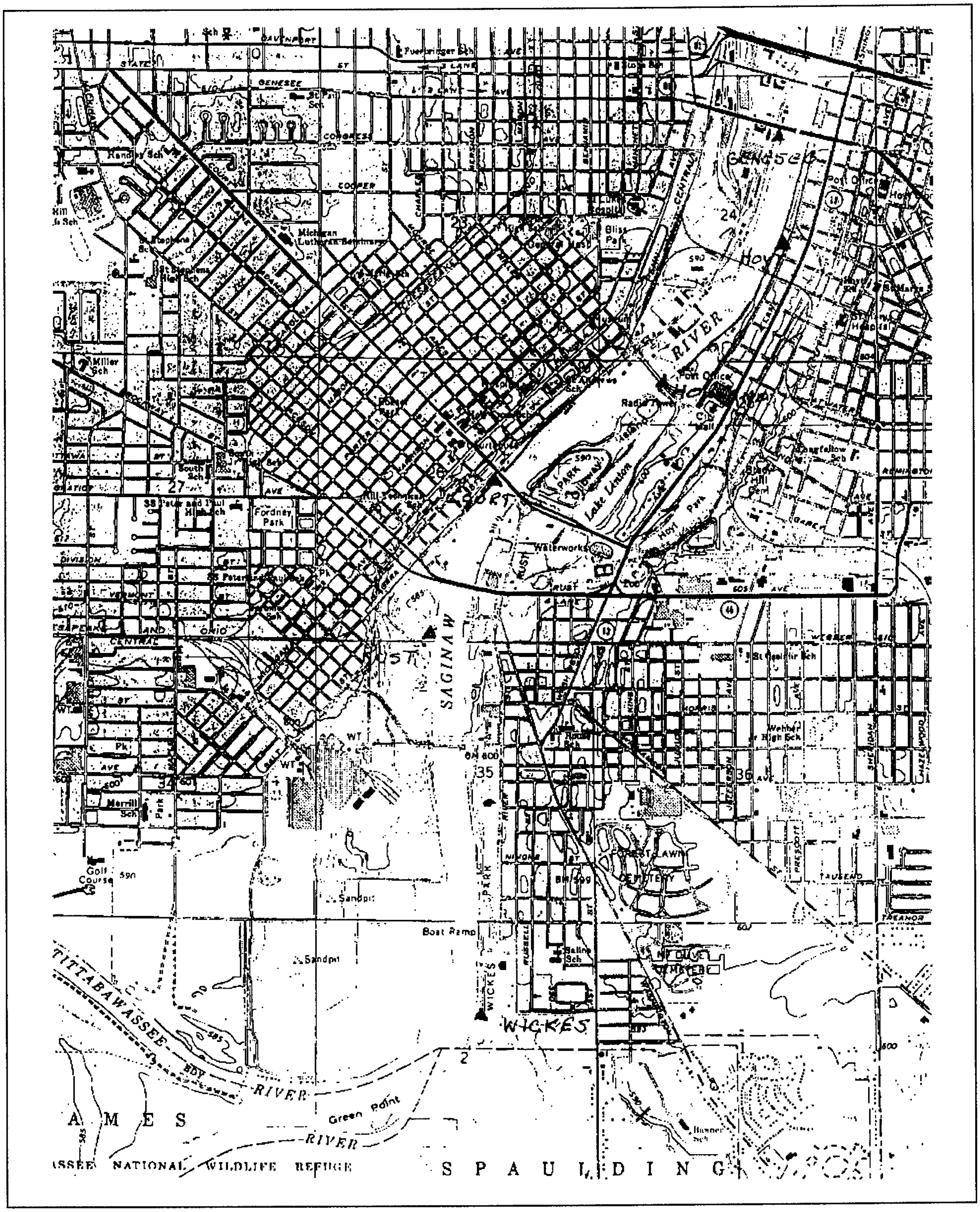


Figure D-17. Project area and control points, Upper Saginaw River project (Continued)

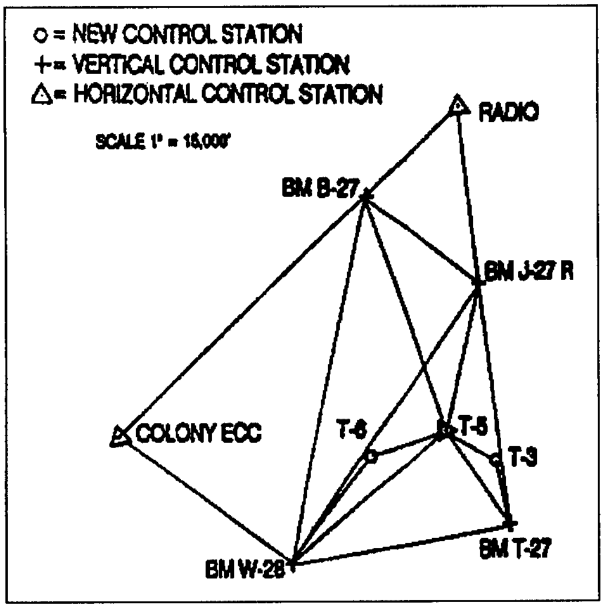


Figure D-17. (Concluded)

support digital mapping of the Upper Saginaw River. Saginaw's function was to provide horizontal control in this area for mapping purposes. Six points (3 pairs) were established, see Figure D-17. Control was brought in from two First-Order NGS horizontal control stations, stations Jonas and Parrish.

c. Four Ashtech Dual Frequency (L1/L2) GPS receivers and antennas with ground planes were used for this project.

d. Prior to any data collection, a preplanning survey was conducted to determine any obstructions (see Figure D-18) and examine existing control. Control station Jonas and Parrish had some sinking problems due to thawing ground. Station Jonas was readjusted during the survey but station Parrish was not.

e. A satellite visibility chart was run to determine occupation times for each session on both day 083 and day 084. The chart included the number of satellites and PDOP for the project area. The charts were run with an elevation mask of 20 deg (see Figure D-19) and 25 deg (see Figure D-20).

f. There were three survey sessions held on day 083 and one on day 084. Table D-5 lists sessions, occupation times, and stations occupied for day 083 and Table D-6 lists day 084 occupation times and stations.

D-11. Actual Survey

The survey was performed as planned, with three sessions on day 083 and one session on day 084. An observation log (see Figure D-21) for each station was recorded by the observer. This information was used during post-processing.

D-12. Data Processing and Adjustment

a. The GPS baselines were processed using Ashtech baseline reduction software (GPPS). All four sessions were processed. An output file from this program is shown in Figure D-22. From these results, session 083 A and B and 084 seemed to be satisfactory. Session 083 C tagged all the float solutions except for the vector between 4008 and 4009. The plots for these vectors, between 4008 and 4009, appeared to have been affected by the ionosphere.

b. After baseline processing was completed, a loop closure was performed to show closures with known control (see Figure D-23) and one was performed to show closures with the unknown control stations.

c. Once the closures were completed, a free adjustment and a constrained adjustment were performed on all processed baselines for Julian days 083 and 084. Figure D-24 was the input file used for the free adjustment. The constrained adjustment held fixed station PARRISH's X,Y,Z and station JONAS' X,Y. The results of the constrained adjustment are listed in Figure D-25.

d. After the final adjustment of the data, CORPSCON was used to convert the station latitude and longitude to state plane coordinates. This file is listed in Figure D-26.

D-13. Station Descriptions

Station descriptions with adjusted coordinates for each control station set were formulated. These are listed in Figure D-27.

" G.P.S. PREPLANNING SURVEY "

PROJECT: UPPER SAGINAW

STATION NAME: HOYT RIGHT OF ENTRY YES DATE:____

HORIZONTAL CONTROL: KNOWN____ UNKNOWN ✓ (IF UNKNOWN GIVE APPROX. LAT/LONG)

IF KNOWN GIVE VALUES: DATUM____ PROJECTION____ ZONE____

LATITUDE____ NORTH____

LONGITUDE____ EAST____

VERTICAL CONTROL: KNOWN____ UNKNOWN ✓ (IF UNKNOWN GIVE APPROX. ELEV.)

IF KNOWN GIVE VALUES: DATUM____ ELEV. FT.____ METERS____

OBSEVATION SITE: COMPLETE OBSTRUCTION POLAR MAP (SEE BELOW)

ACCESSABILITY: CAR/TRUCK ✓ HIKE____ BOAT ✓

DISTANCE VEHICLE CAN BE PARKED TO STATION:____

PRIVATE PROPERTY____ PUBLIC PROPERTY ✓ KEY FOR GATE REQUIRED____

NOTIFICATION OF PROPERTY OWNER REQUIRED PRIOR TO ACCESS NO

NAME: SAG. RIVER WALK IF YES PHONE #____

OBSTRUCTION POLAR MAP:

INDICATE OBSTRUCTIONS:
EX. TREES, BUILDINGS,...
(SEE EXAMPLE ON BACK)

REMARKS:

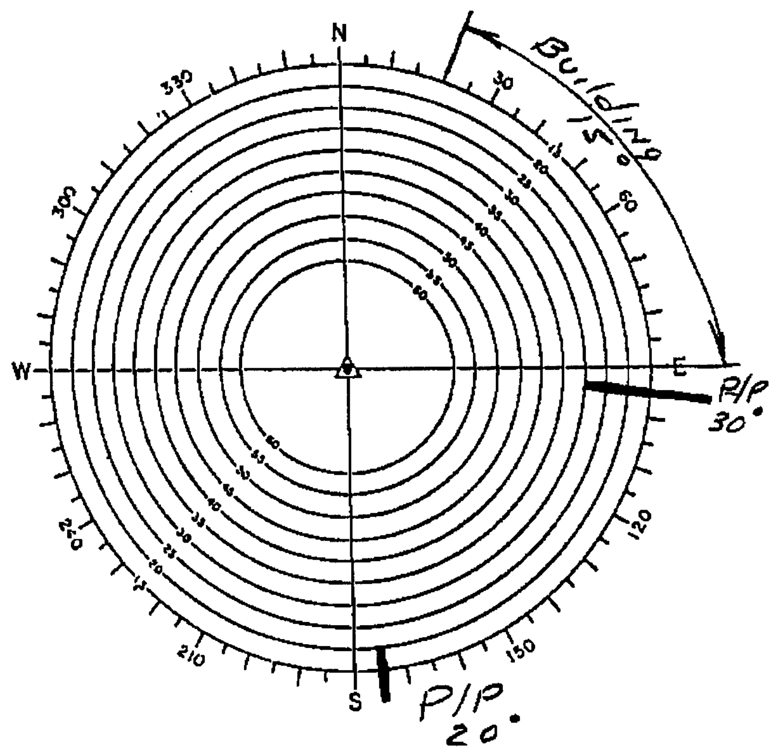


Figure D-18. Preplanning survey, Upper Saginaw River project

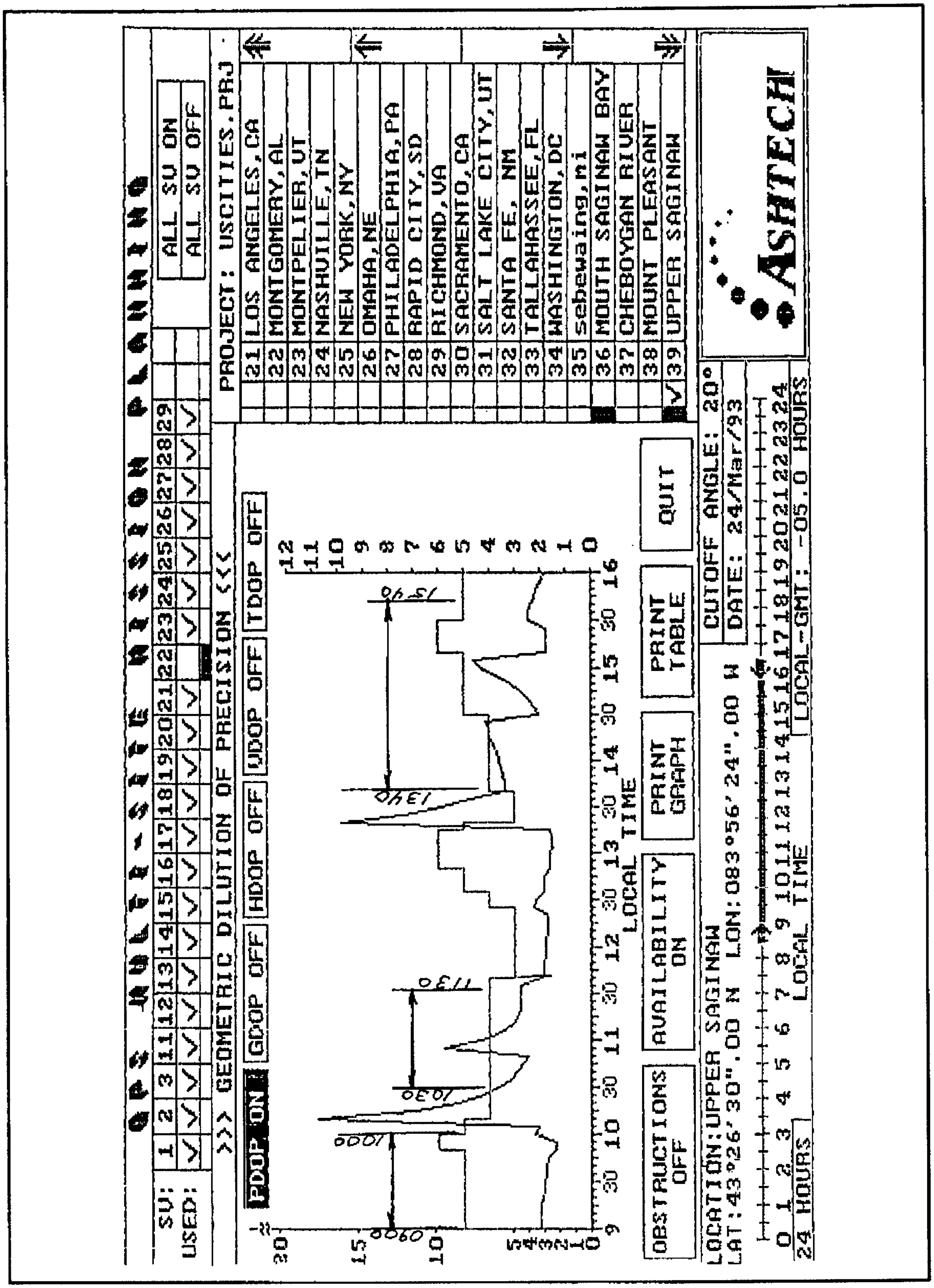


Figure D-19. Satellite visibility chart, elevation mask 20 deg

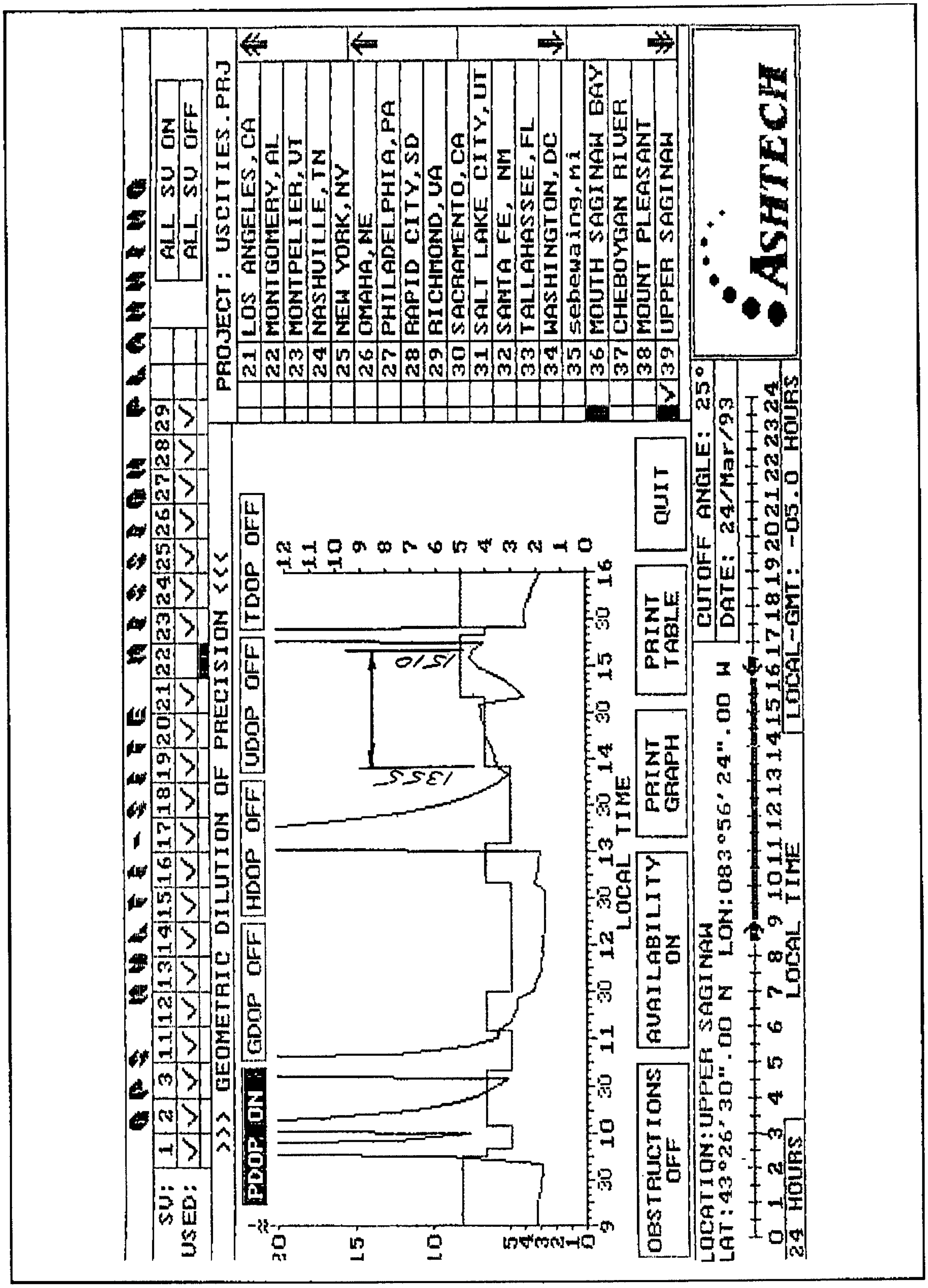


Figure D-20. Satellite visibility chart, elevation mask 25 deg

Table D-5
Day 083

Session A 0900-1000	Session B 1030-1130	Session C 1340-1540
HOYT	WICKES	WICKES
GENESSEE	RUST	RUST
HOLLAND	HOLLAND	JONAS
EWALD	EWALD	PARRISH

Table D-6
Day 084

Session A 1335-1535
HOYT
GENESEE
JONAS
PARRISH

CORPS OF ENGINEERS "GPS OBSERVATION LOG" SAGINAW AREA OFFICE

PROJECT SAG. RIVER LOCATION ____

OBSERVER NAME GREG DATE 3-24-93 JULIAN DATE 083

****

SESSION "A"

STATION NAME: HOYT STATION # 4004

SKED.START 0900 ACTUAL START 0850 SKED.STOP 1000 ACTUAL STOP ____

ANTENNA HEIGHT: INCHES: BEFORE 59 1/4" AFTER 59 1/4" MEAN 59 1/4"

METERS: BEFORE 1.505m AFTER 1.505 MEAN 1.505 ✓

****

SESSION "B"

STATION NAME: WICKES STATION # 4008

SKED.START 1030 ACTUAL START 1030 SKED.STOP 11:30 ACTUAL STOP 1130

ANTENNA HEIGHT: INCHES: BEFORE 62 3/16 AFTER 62 3/16 MEAN 62 3/16"

METERS: BEFORE 1.579 AFTER 1.579 MEAN 1.579 ✓

****

SESSION "C"

STATION NAME: WICKES STATION # 4008

SKED.START 1340 ACTUAL START 1335 SKED.STOP 1540 ACTUAL STOP 1540

ANTENNA HEIGHT: INCHES: BEFORE 64 3/8" AFTER 64 3/8" MEAN 64 3/8"

METERS: BEFORE 1.636 AFTER 1.636 MEAN 1.636 ✓

****

SESSION "D"

STATION NAME: ____ STATION # ____

SKED.START ____ ACTUAL START ____ SKED.STOP ____ ACTUAL STOP ____

ANTENNA HEIGHT: INCHES: BEFORE ____ AFTER ____ MEAN ____

METERS: BEFORE ____ AFTER ____ MEAN ____

****

RECEIVER INFORMATION

S/N 501 ANTENNA # 001 ANT. CABLE LENGTH 50' POWER SUPPLY 24V

GROUND PLANES USED YES L1 YES L2 YES

****

COMMENTS: (WEATHER, PROBLEMS, OCCURENCES, ?)

SESSION "A" REC. SV #'s 01-12-15-20-21-23-25 (LOST #23-0910
" #12-0915
GAIN #14-0920)

SESSION "B" " " # 01-14-15-20-25-29 (LOST #15-1045
" #20-1120)

SESSION "C" " " # 03-14-18-19-25-28-29 (LOST #14-1350 OVER

Figure D-21. Observation log, Upper Saginaw River project

```
Ashtech, Inc. GPPS-L          Program: LINECOMP         Version: 4.5.00
                              Fri Mar 26 10:34:33 1993

Project information
GPS Survey               |25-character project name  [ The | is in column 26
. ]
0843A                    |5-character session name
Project information

Known-station parameters
00                       |Receiver identifier used in "LOGTIMES" file
000000                   |Project station number
1001                     |4-character short name
FIXED STATION            |25-character long name
503 003 005 ____________ |25-character comment field
0                        |Position extraction (0=below,1=U-file,2=proj. file
)
N  43 33 32.67131        |Latitude deg-min-sec   (g=good;b=bad)
E 276 11 32.13854        |E-Longitude deg-min-sec (g=good;b=bad)
W  83 48 27.86146        |W-Longitude deg-min-sec (g=good;b=bad)
   150.7356              |Ellipsoidal height  (m) (g=good;b=bad)
     0.0000              |North antenna offset(m)
     0.0000              |East antenna offset (m)
  1.6990  0.1150  0.0000 |Vert antenna offset (m): slant/radius/added_offset
    20.0                 |Temperature (degrees C)
    50.0                 |Humidity (percent)
  1010.0                 |Pressure (millibars)
U1001A93.084             |Measurement filename (restricted to 24 characters)
Known-station parameters

Unknown-station parameters
00                       |Receiver identifier used in "LOGTIMES" file
000000                   |Project station number
4005                     |4-character short name
UNKNOWN STATION          |25-character long name
504 004 007 ____________ |25-character comment field
0                        |Position extraction (0=below,1=U-file,2=proj. file
)
N  43 26  1.65174        |Latitude deg-min-sec   (g=good;b=bad)
E 276  3 25.93899        |E-Longitude deg-min-sec (g=good;b=bad)
W  83 56 34.06101        |W-Longitude deg-min-sec (g=good;b=bad)
   149.5289              |Ellipsoidal height  (m) (g=good;b=bad)
     0.0000              |North antenna offset(m)
     0.0000              |East antenna offset (m)
  1.6350  0.1150  0.0000 |Vert antenna offset (m): slant/radius/added_offset
    20.0                 |Temperature (degrees C)
    50.0                 |Humidity (percent)
  1010.0                 |Pressure (millibars)
U4005A93.084             |Measurement filename (restricted to 24 characters)
Unknown-station parameters
```

Figure D-22. Output file, Upper Saginaw River project (Ashtech) (Sheet 1 of 5)

```
Run-time parameters
    1                      |First epoch to process
   -1                      |Final epoch to process (-1 = last available)
20.0                       |Elevation cutoff angle (degrees)
1                          |Data to process (0=Wdln;1=L1;2=L2;3=L1c;6=RpdSt)
0.010000                   |Convergence criterion (meters)
00 00 00 00 00 00 00       |Omit these satellites (up to 7)
10                         |Maximum iterations for tlsq and dlsq
00 00 00 00 00 00 00       |Forbidden reference SVs (up to 7)
yes                        |Apply tropo delay correction
Run-time parameters

LINECOMP 4.5.00 12/11/92

FIXED U-File from L1 only receiver.
UNKWN U-File from L1 only receiver.

FIXED U-File used BROADCAST orbits.
UNKWN U-File used BROADCAST orbits.

Common start of two UFILES: 1993/03/25 18:35:60.00
Common end   of two UFILES: 1993/03/25 20:32:60.00
    Selected first epoch:  1
    Selected last  epoch:  352
For SV 11 there are   221 triple-difference measurements.
For SV 18 there are   351 triple-difference measurements.
For SV 19 there are   351 triple-difference measurements.
For SV 27 there are    73 triple-difference measurements.
For SV 28 there are   348 triple-difference measurements.
For SV 29 there are   338 triple-difference measurements.
Epoch interval (seconds): 20.000000


THE TRIPLE DIFFERENCE SOLUTION (L1)
Measure of geometry: 0.640415
num_meas =  1329        num_used =  1323        rms_resid = 0.002595(m)
Post-Fit Chisq =  3459.383          NDF      =    12.250


  Sigmax (m):       0.870234
  Sigmay (m):       0.572256
  Sigmaz (m):       0.270963
  x      y      z
x 1.00
y 0.71y 1.00
z-0.40z-0.59z 1.00

del_station: 0.005074 0.001394 -0.000650
     Station1: FIXED STATION             Station2: UNKNOWN STATION

                (00000)    (1001)                  (00000)    (4005)
```

Figure D-22. (Sheet 2 of 5)

```
Latitude:  43.55907536  43 33 32.67131         43.43379221  43 26  1.65195

E-Long   : 276.19226071 276 11 32.13854       276.05720501 276  3 25.93803

W-Long   :  83.80773929  83 48 27.86146        83.94279499  83 56 34.06197

E-Height: 150.7356                             149.5416

Baseline vector:     -9839.2603    -10690.9170    -10098.3296

Mark1_xyz   :    499359.2995  -4602470.6194   4372824.2683
Az1 El1 D1  :      218.17046        -0.0834     17694.1519
E1 N1 U1    :    -10912.4583    -13919.7439        -1.1940
Mark2_xyz   :    489520.0392  -4613161.5364   4362725.9387
Az2 El2 D2  :       38.07750        -0.0757     17694.1519
E2 N2 U2    :     10935.0401     13919.4351         1.1940

Double-Difference Epochs:
  Prn:  11  Start epoch:  132  End epoch:  352
  Prn:  18  Start epoch:    2  End epoch:  352
  Prn:  19  Start epoch:    2  End epoch:  352
  Prn:  27  Start epoch:  280  End epoch:  352
  Prn:  28  Start epoch:    5  End epoch:  352
  Prn:  29  Start epoch:    2  End epoch:  339


THE FLOAT DOUBLE DIFFERENCE SOLUTION (L1)
Measure of geometry: 0.103203    Wavelength = 0.190294 (m/cycle)
num_meas =  1332        num_used =  1317         rms_resid = 0.004061(m)
Post-Fit Chisq =    42.171          NDF      =    12.194

Reference SV: 18
  SV     Ambiguity          FIT    Meas       SV     Ambiguity         FIT    Meas
  11      22406589.878f    0.024   211        19      21161231.999f   0.018   350
  27      10785453.076f    0.024    72        28      28836460.832f   0.022   348
  29       5129536.945f    0.021   336

  Sigmax (m):       0.015558
  Sigmay (m):       0.010159
  Sigmaz (m):       0.004803
  SigmaN (cy):      0.075992
  SigmaN (cy):      0.018403
  SigmaN (cy):      0.034642
  SigmaN (cy):      0.089934
  SigmaN (cy):      0.033807
  x     y     z     N     N     N     N     N
x 1.00
y 0.72y 1.00
z-0.50z-0.65z 1.00
N 0.97N 0.72N-0.59N 1.00
N-0.10N 0.42N-0.05N-0.05N 1.00
```

Figure D-22. (Sheet 3 of 5)

```
N-0.31N 0.26N-0.05N-0.26N 0.67N 1.00
N 0.99N 0.76N-0.52N 0.98N-0.00N-0.24N 1.00
N 0.89N 0.57N-0.60N 0.93N-0.11N-0.32N 0.90N 1.00

del_station: 0.000000 0.000000 0.000000
     Station1: FIXED STATION                   Station2: UNKNOWN STATION

                (00000)    (1001)                   (00000)    (4005)
 Latitude:  43.55907536  43 33 32.67131         43.43379217  43 26  1.65179

 E-Long  : 276.19226071 276 11 32.13854        276.05720515 276  3 25.93854

 W-Long  :  83.80773929  83 48 27.86146         83.94279485  83 56 34.06146

 E-Height: 150.7356                             149.5272

 Baseline vector:     -9839.2497    -10690.9086    -10098.3429

 Mark1_xyz   :    499359.2995  -4602470.6194   4372824.2683
 Az1 El1 D1  :       218.17042        -0.0834     17694.1485
 E1 N1 U1    :    -10912.4468    -13919.7486        -1.2084
 Mark2_xyz   :    489520.0498  -4613161.5280   4362725.9254
 Az2 El2 D2  :        38.07746        -0.0756     17694.1485
 E2 N2 U2    :     10935.0287     13919.4398         1.2084


AMBIGUITY RESOLUTION
                             1          2          3          4
Abs Contrast             0.008      0.000      0.000      0.000
Contrast                          100.000    100.000    100.000
Change Chi2             38.426   4588.301   4624.842   5296.077
Bias S18:11           22406590   22406591   22406589   22406590
Bias S18:19           21161232   21161232   21161232   21161232
Bias S18:27           10785453   10785453   10785453   10785454
Bias S18:28           28836461   28836462   28836460   28836461
Bias S18:29            5129537    5129537    5129537    5129537
NDF=136.7000 Chi2=42.1709


THE FIXED DOUBLE DIFFERENCE SOLUTION (L1)
Measure of geometry: 0.030142     Wavelength = 0.190294 (m/cycle)
num_meas =  1332          num_used =  1315          rms_resid = 0.005514(m)
Post-Fit Chisq =     77.434           NDF      =     12.176

Reference SV: 18                   Integer Search Ratio =  100.000
  SV      Ambiguity        FIT    Meas      SV      Ambiguity       FIT    Meas
  11      22406590.000X  0.031    213       19      21161232.000X  0.029    350
  27      10785453.000X  0.053     65       28      28836461.000X  0.025    349
  29       5129537.000X  0.024    338

  Sigmax (m):       0.002257
```

Figure D-22. (Sheet 4 of 5)

```
  Sigmay (m):       0.005658
  Sigmaz (m):       0.004546
  x     y     z
x 1.00
y 0.19y 1.00
z 0.12z-0.72z 1.00

del_station: 0.000016 0.000949 -0.000715
     Station1: FIXED STATION                    Station2: UNKNOWN STATION

                 (00000)     (1001)                    (00000)     (4005)
 Latitude:  43.55907536  43 33 32.67131          43.43379220  43 26  1.65191

 E-Long   : 276.19226071 276 11 32.13854        276.05720552 276  3 25.93986

 W-Long   :  83.80773929  83 48 27.86146         83.94279448  83 56 34.06014

 E-Height: 150.7356                              149.5220

 Baseline vector:      -9839.2208     -10690.8991    -10098.3438

 Mark1_xyz  :    499359.2995  -4602470.6194   4372824.2683
 Az1 El1 D1 :       218.17035        -0.0835    17694.1272
 E1 N1 U1   :   -10912.4172    -13919.7449        -1.2136
 Mark2_xyz  :    489520.0787  -4613161.5185   4362725.9246
 Az2 El2 D2 :        38.07739        -0.0756    17694.1272
 E2 N2 U2   :     10934.9990     13919.4360         1.2136
Fri Mar 26 10:39:26 1993
```

Figure D-22. (Sheet 5 of 5)

```
 PROGRAM SHOOTER
Input: FILLNET.IN                          Output: 083084aa.lop

STARTING STATION NAME: 1001
 LINE FROM           TO                   DX          DY          DZ          LENGTH
   1  1001           4008      0833C  -11172.423  -14312.145  -13760.192   22781.646
  17  4008           4009      0833B    -412.530    1492.440    1614.982    2237.348
  14  4007           4009      0833B    -313.662    -602.201    -613.237     914.926
  11  4006           4007      0833A    -864.616    -467.386    -388.225    1056.754
   9  4006           4004      0833A     628.445     613.864     569.761    1047.091
  24  4005           4004      0843A      60.920    -445.464    -475.513     654.417
  20  1001           4005      0843A   -9839.221  -10690.899  -10098.344   17694.127

      STATION              LATITUDE         LONGITUDE        ELEV.       GH
      1001             43 33 32.67152    83 48 27.85821    150.615      0.000
      4008             43 23 18.39708    83 57 49.93702    146.842      0.000
      4009             43 24 30.42613    83 58  1.19491    146.545      0.000
      4007             43 24 57.46166    83 57 44.51670    156.913      0.000
      4006             43 25 14.92267    83 57  4.10971    152.264      0.000
      4004             43 25 40.45135    83 56 33.44979    148.694      0.000
      4005             43 26  1.65131    83 56 34.05326    149.238      0.000
      1001             43 33 32.67072    83 48 27.85454    150.452      0.000

 TRAVERSE LENGTH =  46.386 kilometers
 MISCLOSURES (LAT., LON., ELEV., meters):    -0.025   -0.082   -0.163
                                                  LOOP MISCLOSURE =   4.0 ppm
   Since geoid heights are not given, the
   computed elevations may be seriously in error.


STARTING STATION NAME: 1002
 LINE FROM           TO                   DX          DY          DZ          LENGTH
  23  1002           4005      0843A    7853.486  -20463.167  -22275.296   31250.716
  10  4006           4005      0833A     567.529    1059.329    1045.274    1592.754
  12  4006           4007      0833B    -864.618    -467.386    -388.229    1056.757
  16  4008           4007      0833B     -98.867    2094.641    2228.220    3059.781
  18  4009           4008      0833C     412.552   -1492.436   -1614.997    2237.360
  13  4006           4009      0833B   -1178.280   -1069.587   -1001.466    1880.238
   9  4006           4004      0833A     628.445     613.864     569.761    1047.091
  24  4005           4004      0843A      60.920    -445.464    -475.513     654.417
   8  4005           4007      0833A   -1432.144   -1526.716   -1433.499    2537.088
  14  4007           4009      0833B    -313.662    -602.201    -613.237     914.926
   5  1002           4009      0833C    6107.640  -22591.898  -24322.208   33753.028

      STATION              LATITUDE         LONGITUDE        ELEV.       GH
      1002             43 42 37.45123    84 00 46.44187    162.300      0.000
      4005             43 26  1.65174    83 56 34.06100    149.529      0.000
      4006             43 25 14.92309    83 57  4.11762    152.555      0.000
      4007             43 24 57.46199    83 57 44.52470    157.201      0.000
      4008             43 23 18.39740    83 57 49.94506    147.130      0.000
```

Figure D-23. Loop closure, Upper Saginaw River project (Continued)

```
    4009              43 24 30.42676   83 58  1.20394   146.844     0.000
    4006              43 25 14.92339   83 57  4.11865   152.566     0.000
    4004              43 25 40.45206   83 56 33.45874   148.995     0.000
    4005              43 26  1.65202   83 56 34.06221   149.540     0.000
    4007              43 24 57.46234   83 57 44.52579   157.216     0.000
    4009              43 24 30.42681   83 58  1.20400   146.848     0.000
    1002              43 42 37.45140   84 00 46.44218   162.570     0.000

TRAVERSE LENGTH =  79.984 kilometers
MISCLOSURES (LAT., LON., ELEV., meters):    0.005   0.007   0.270
                                        LOOP MISCLOSURE =   3.4 ppm
   Since geoid heights are not given, the
   computed elevations may be seriously in error.
```

Figure D-23. (Concluded)

FILLNET.IN

```
6378137.0   298.2572221  W     Y A 50 Y N N N N
Fillnet Input File  083084 FREE ADJ     43.5  83.9
    1001            43 33 32.67152  083 48 27.85821   150.615
  1   0
    4008            43 23 18.39709  083 57 49.93704   146.842
  2   0
    4009            43 24 30.42636  083 58  1.19634   146.561
  3   0
FFF 1002            43 42 37.45123  084  0 46.44187   162.300
  4   0
    4004            43 25 40.44276  083 56 33.45850   148.717
  5   0
    4005            43 26  1.64290  083 56 34.06171   149.245
  6   0
    4007            43 24 57.45316  083 57 44.52581   156.933
  7   0
    4006            43 25 14.91409  083 57  4.11839   152.287
  8   0
*
  24 3 510   510 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
  4 1001            4008      0833C  -11172.423 -14312.145 -13760.192  610201020
  1   2
  4 1001            4009      0833C  -11584.984 -12819.715 -12145.194  610201020
  1   3
  4 1002            1001      0833C   17692.643  -9772.176 -12177.017  610201020
  4   1
  4 1002            4008      0833C    6520.196 -24084.335 -25937.204  610201020
  4   2
  4 1002            4009      0833C    6107.640 -22591.898 -24322.208  610201020
  4   3
  4 4004            4005      0833A     -60.916    445.465    475.513
  5   6
  4 4004            4007      0833A   -1493.060  -1081.250   -957.986
  5   7
  4 4005            4007      0833A   -1432.144  -1526.716  -1433.499
  6   7
  4 4006            4004      0833A     628.445    613.864    569.761
  8   5
  4 4006            4005      0833A     567.529   1059.329   1045.274
  8   6
  4 4006            4007      0833A    -864.616   -467.386   -388.225
  8   7
  4 4006            4007      0833B    -864.618   -467.386   -388.229
  8   7
  4 4006            4009      0833B   -1178.280  -1069.587  -1001.466
  8   3
  4 4007            4009      0833B    -313.662   -602.201   -613.237
  7   3
  4 4008            4006      0833B     765.751   2562.026   2616.450
  2   8
  4 4008            4007      0833B     -98.867   2094.641   2228.220
  2   7
  4 4008            4009      0833B    -412.530   1492.440   1614.982
  2   3
  4 4009            4008      0833C     412.552  -1492.436  -1614.997
  3   2
  4 1001            4004      0843A   -9778.301 -11136.364 -10573.856
```

Figure D-24. Input file for free adjustment, Upper Saginaw River project (Continued)

FILLNET.IN

```
1    5
4 1001          4005     0843A    -9839.221 -10690.899 -10098.344
1    6
4 1002          1001     0843A    17692.725  -9772.257 -12176.953
4    1
4 1002          4004     0843A     7914.403 -20908.632 -22750.807
4    5
4 1002          4005     0843A     7853.486 -20463.167 -22275.296
4    6
4 4005          4004     0843A       60.920   -445.464   -475.513
6    5
```

Figure D-24. (Concluded)

```
 PROGRAM FILLNET, Version 3.0.00
 LICENSED TO: ASHTECH INC.


 Fillnet Input File  083084 CONSTRAINED      43.5    83.9

 a =   6378137.000     1/f =  298.2572221   W      Longitude positive WE
ST

 PRELIMINARY COORDINATES:
                             LAT.                LON.          ELEV.     G.H.   CON
STR.

   1  FF     1001 43 33 32.66675    83 48 27.86095    150.615    0.000
   2         4008 43 23 18.39709    83 57 49.93704    146.842    0.000
   3         4009 43 24 30.42636    83 58  1.19634    146.561    0.000
   4  FFF    1002 43 42 37.45123    84  0 46.44187    162.300    0.000
   5         4004 43 25 40.44276    83 56 33.45850    148.717    0.000
   6         4005 43 26  1.64290    83 56 34.06171    149.245    0.000
   7         4007 43 24 57.45316    83 57 44.52581    156.933    0.000
   8         4006 43 25 14.91409    83 57  4.11839    152.287    0.000

 GROUP 1, NO. OF VECTORS AND BIAS CONSTRAINTS:

  24      0.000  0.001    0.000  0.001    0.000  0.000    0.000  0.000

 VECTORS:
                        DX          DY          DZ       LENGTH    ERROR CODES

 1001      4008   -11172.423 -14312.145 -13760.192  22781.646   6102.0 102.
0  4
 1001      4009   -11584.984 -12819.715 -12145.194  21120.196   6102.0 102.
0  4
 1002      1001    17692.643  -9772.176 -12177.017  23596.711   6102.0 102.
0  4
 1002      4008     6520.196 -24084.335 -25937.204  35990.370   6102.0 102.
0  4
 1002      4009     6107.640 -22591.898 -24322.208  33753.028   6102.0 102.
0  4
 4004      4005      -60.916    445.465    475.513    654.418   3 51.0   51.
0  4
 4004      4007    -1493.060  -1081.250   -957.986   2077.515   3 51.0   51.
0  4
 4005      4007    -1432.144  -1526.716  -1433.499   2537.088   3 51.0   51.
0  4
 4006      4004      628.445    613.864    569.761   1047.091   3 51.0   51.
0  4
 4006      4005      567.529   1059.329   1045.274   1592.754   3 51.0   51.
0  4
 4006      4007     -864.616   -467.386   -388.225   1056.754   3 51.0   51.
0  4
```

Figure D-25. Results of constrained adjustment, Upper Saginaw River project (Sheet 1 of 6)

```
 4006    4007    -864.618    -467.386    -388.229    1056.757  3 51.0   51.
0  4
 4006    4009   -1178.280   -1069.587   -1001.466    1880.238  3 51.0   51.
0  4
 4007    4009    -313.662    -602.201    -613.237     914.926  3 51.0   51.
0  4
 4008    4006     765.751    2562.026    2616.450    3741.145  3 51.0   51.
0  4
 4008    4007     -98.867    2094.641    2228.220    3059.781  3 51.0   51.
0  4
 4008    4009    -412.530    1492.440    1614.982    2237.348  3 51.0   51.
0  4
 4009    4008     412.552   -1492.436   -1614.997    2237.360  3 51.0   51.
0  4
 1001    4004   -9778.301  -11136.364  -10573.856   18205.499  3 51.0   51.
0  4
 1001    4005   -9839.221  -10690.899  -10098.344   17694.127  3 51.0   51.
0  4
 1002    1001   17692.725   -9772.257  -12176.953   23596.773  3 51.0   51.
0  4
 1002    4004    7914.403  -20908.632  -22750.807   31896.832  3 51.0   51.
0  4
 1002    4005    7853.486  -20463.167  -22275.296   31250.716  3 51.0   51.
0  4
 4005    4004      60.920    -445.464    -475.513     654.417  3 51.0   51.
0  4

   SHIFTS:
     1   0.000   0.000   0.102
     2  -0.190  -0.260   0.238
     3  -0.181  -0.230   0.226
     4   0.000   0.000   0.000
     5   0.097  -0.045   0.222
     6   0.095  -0.047   0.238
     7   0.091  -0.049   0.223
     8   0.095  -0.051   0.222

 ADJUSTED VECTORS, GROUP 1:
                                DX,DY,DZ    V        DN,DE,DU     v       v'

 1001    4008     0833C    -11172.608 -0.063  -18960.149  0.017    0.3
                           -14312.293 -0.093  -12630.231 -0.073   -1.1
                           -13760.130  0.105     -10.059  0.135    2.0

 1001    4009     0833C    -11585.141 -0.039  -16736.980  0.014    0.2
                           -12819.845 -0.085  -12881.834 -0.048   -0.8
                           -12145.133  0.095      -6.620  0.124    2.0

 1002    1001     0833C     17692.745  0.058  -16815.857 -0.014   -0.2
                            -9772.339 -0.070   16554.120  0.051    0.7
                           -12177.068  0.052      30.106  0.090    1.3
```

Figure D-25. (Sheet 2 of 6)

1002	4008	0833C	6520.137	0.019	-35776.006	0.007	0.1
			-24084.632	-0.149	3923.889	0.003	0.0
			-25937.198	0.152	20.048	0.214	2.1
1002	4009	0833C	6107.605	0.038	-33552.837	0.000	0.0
			-22592.184	-0.148	3672.286	0.022	0.2
			-24322.201	0.144	23.486	0.208	2.2
4004	4005	0833A	-60.916	-0.001	654.286	-0.000	-0.0
			445.467	-0.000	-13.234	-0.001	-0.2
			475.516	0.000	1.327	0.000	0.0
4004	4007	0833A	-1493.074	-0.001	-1325.757	-0.001	-0.2
			-1081.252	0.001	-1599.518	-0.001	-0.2
			-957.990	-0.002	5.347	-0.002	-0.3
4005	4007	0833A	-1432.158	0.000	-1980.043	-0.000	-0.0
			-1526.719	0.002	-1586.285	0.000	0.0
			-1433.505	-0.002	4.020	-0.003	-0.4
4006	4004	0833A	628.451	-0.000	787.486	-0.000	-0.1
			613.865	-0.001	690.124	-0.000	-0.1
			569.763	0.000	-2.121	0.001	0.1
4006	4005	0833A	567.535	-0.002	1441.772	-0.000	-0.1
			1059.333	-0.001	676.890	-0.002	-0.3
			1045.278	0.000	-0.794	0.001	0.1
4006	4007	0833A	-864.623	-0.001	-538.271	-0.001	-0.3
			-467.387	0.000	-909.394	-0.001	-0.1
			-388.227	-0.002	3.227	-0.002	-0.2
4006	4007	0833B	-864.623	0.001	-538.271	0.001	0.3
			-467.387	0.000	-909.394	0.001	0.2
			-388.227	0.002	3.227	0.001	0.2
4006	4009	0833B	-1178.293	-0.003	-1372.338	0.002	0.3
			-1069.590	0.001	-1285.281	-0.002	-0.3
			-1001.467	0.001	-8.729	0.000	0.0
4007	4009	0833B	-313.670	-0.004	-834.066	0.000	0.1
			-602.203	0.001	-375.887	-0.004	-0.5
			-613.240	-0.000	-11.955	-0.001	-0.1
4008	4006	0833B	765.761	-0.006	3595.507	0.001	0.2
			2562.037	-0.001	1033.678	-0.006	-0.7
			2616.464	0.002	12.167	0.002	0.2
4008	4007	0833B	-98.862	-0.004	3057.236	0.003	0.4
			2094.651	-0.002	124.284	-0.005	-0.6

Figure D-25. (Sheet 3 of 6)

```
                                2228.237   0.005       15.393   0.005     0.6

4008     4009      0833B        -412.532  -0.007     2223.169   0.004     0.7
                                1492.448  -0.002     -251.603  -0.007    -1.0
                                1614.997   0.006        3.438   0.004     0.6

4009     4008      0833C         412.532  -0.015    -2223.169   0.006     1.2
                               -1492.448  -0.002      251.603  -0.015    -1.9
                               -1614.997   0.009       -3.438   0.007     0.9

1001     4004      0843A       -9778.397   0.005   -14577.156  -0.004    -0.1
                              -11136.390   0.014   -10906.429   0.006     0.2
                              -10573.904  -0.017       -0.012  -0.022    -0.8

1001     4005      0843A       -9839.312   0.007   -13922.870  -0.003    -0.1
                              -10690.923   0.013   -10919.663   0.009     0.3
                              -10098.389  -0.016        1.314  -0.020    -0.8

1002     1001      0843A       17692.745  -0.024   -16815.857   0.001     0.0
                               -9772.339   0.011    16554.120  -0.022    -0.7
                              -12177.068  -0.012       30.106  -0.019    -0.5

1002     4004      0843A        7914.349   0.002   -31393.013   0.001     0.0
                              -20908.729   0.036     5647.691   0.006     0.1
                              -22750.972  -0.032       30.094  -0.048    -1.0

1002     4005      0843A        7853.433   0.002   -30738.727   0.003     0.1
                              -20463.262   0.036     5634.457   0.005     0.1
                              -22275.456  -0.030       31.421  -0.046    -1.0

4005     4004      0843A          60.916  -0.003     -654.286  -0.000    -0.1
                                -445.467  -0.001       13.234  -0.003    -0.4
                                -475.516  -0.000       -1.327   0.000     0.0

S.E. OF UNIT WEIGHT =     0.843

NUMBER OF -
  OBS. EQUATIONS               74
  UNKNOWNS                     23
  DEGREES OF FREEDOM           51
  ITERATIONS                    0


GROUP  1 ROT. ANGLES (sec.) AND SCALE DIFF. (ppm):

HOR. SYSTEM          0.000    0.000    0.657    5.277
STD. ERRORS          0.001    0.001    0.166    0.804
XYZ SYSTEM           0.051   -0.473    0.452

ADJUSTED POSITIONS:
```

Figure D-25. (Sheet 4 of 6)

```
                     LAT.                  LON.              ELEV.     STD. ERRORS
(m)

   1   1001      43 33 32.66675     83 48 27.86095     150.717 0.000 0.000 0.
019
   2   4008      43 23 18.39093     83 57 49.94860     147.080 0.024 0.024 0.
019
   3   4009      43 24 30.42050     83 58  1.20657     146.787 0.022 0.023 0.
019
   4   1002      43 42 37.45123     84  0 46.44187     162.300 0.000 0.000 0.
000
   5   4004      43 25 40.44591     83 56 33.46051     148.939 0.020 0.020 0.
019
   6   4005      43 26  1.64599     83 56 34.06378     149.483 0.020 0.020 0.
019
   7   4007      43 24 57.45612     83 57 44.52799     157.156 0.022 0.022 0.
019
   8   4006      43 25 14.91718     83 57  4.12068     152.509 0.021 0.021 0.
019

 ACCURACIES (m):
                                          D. LAT.     D. LON.     VERT.

   1001             4008                   0.024       0.024       0.014
   1001             4009                   0.022       0.023       0.014
   1002             1001                   0.000       0.000       0.019
   1002             4008                   0.024       0.024       0.019
   1002             4009                   0.022       0.023       0.019
   4004             4005                   0.002       0.004       0.004
   4004             4007                   0.003       0.004       0.004
   4005             4007                   0.003       0.004       0.004
   4006             4004                   0.003       0.004       0.004
   4006             4005                   0.003       0.004       0.004
   4006             4007                   0.002       0.003       0.003
   4006             4007                   0.002       0.003       0.003
   4006             4009                   0.003       0.004       0.004
   4007             4009                   0.003       0.004       0.004
   4008             4006                   0.004       0.005       0.004
   4008             4007                   0.004       0.005       0.004
   4008             4009                   0.003       0.004       0.004
   4009             4008                   0.003       0.004       0.004
   1001             4004                   0.020       0.020       0.014
   1001             4005                   0.020       0.020       0.014
   1002             1001                   0.000       0.000       0.019
   1002             4004                   0.020       0.020       0.019
   1002             4005                   0.020       0.020       0.019
   4005             4004                   0.002       0.004       0.004


*******************************************************************
****                                                          ****
```

Figure D-25. (Sheet 5 of 6)

```
****                 ESTIMATES OF PRECISION                       ****
****                                                              ****
****      Based on the VECTOR ACCURACIES produced by              ****
****                          FILLNET                             ****
****                                                              ****
****     This is a reasonable estimate of the accuracies          ****
****      of the vectors in the network at 1 SIGMA.               ****
****                                                              ****
**********************************************************************
```

VECTOR		LENGTH	PPM(h)	RATIO(h)	PPM(v)	RATIO(v)
1001	4008	22781.793	1.5	1: 671215	0.6	1: 1627271
1001	4009	21120.326	1.5	1: 663584	0.7	1: 1508595
1002	1001	23596.882	0.0	1: 0	0.8	1: 1241941
1002	4008	35990.553	0.9	1: 1060382	0.5	1: 1894240
1002	4009	33753.209	0.9	1: 1060499	0.6	1: 1776485
4004	4005	654.421	6.8	1: 146333	6.1	1: 163605
4004	4007	2077.527	2.4	1: 415504	1.9	1: 519382
4005	4007	2537.102	2.0	1: 507420	1.6	1: 634275
4006	4004	1047.096	4.8	1: 209419	3.8	1: 261774
4006	4005	1592.761	3.1	1: 318552	2.5	1: 398190
4006	4007	1056.761	3.4	1: 293091	2.8	1: 352254
4006	4007	1056.761	3.4	1: 293091	2.8	1: 352254
4006	4009	1880.249	2.7	1: 376046	2.1	1: 470062
4007	4009	914.932	5.5	1: 182971	4.4	1: 228733
4008	4006	3741.164	1.7	1: 584269	1.1	1: 935291
4008	4007	3059.800	2.1	1: 477854	1.3	1: 764950
4008	4009	2237.364	2.2	1: 447472	1.8	1: 559341
4009	4008	2237.364	2.2	1: 447472	1.8	1: 559341
1001	4004	18205.594	1.6	1: 643665	0.8	1: 1300400
1001	4005	17694.218	1.6	1: 625585	0.8	1: 1263873
1002	1001	23596.882	0.0	1: 0	0.8	1: 1241941
1002	4004	31897.000	0.9	1: 1127729	0.6	1: 1678789
1002	4005	31250.879	0.9	1: 1104885	0.6	1: 1644783
4005	4004	654.421	6.8	1: 146333	6.1	1: 163605

Figure D-25. (Sheet 6 of 6)

```
                                         083084C.SPC
;Software: CORPSCON v3.01, Agency: CORPS OF ENGINEERS SAGINAW
;Project: UPPER SAGINAW MAPPING,
;Original Coordinates on NAD 83 Geographic Coordinates
;Translated Coordinates on NAD 83 State Plane Zone 2113,U.S. FOOT

1001 JONAS           ,13271491.47735,  750899.10875
4008 WICKS           ,13230401.67183,  688469.29439
4009 RUST            ,13229535.79827,  695757.90291
1002 PARRISH         ,13216876.80162,  805765.50958
4004 HOYT            ,13235976.88650,  702879.28348
4005 GENESSEE        ,13235921.56530,  705025.46304
4007 EWALD           ,13230753.74995,  698500.99009
4006 HOLLAND         ,13233727.24329,  700283.34945
```

Figure D-26. CORPSCON file, Upper Saginaw River project

U.S. ARMY ENGINEER DISTRICT - DETROIT

GENERAL INFORMATION

designation: HOYT
reference no. SAG-0613

project: SAGINAW RIVER
channel/reach: UPPER
sheet no.
USGS Quad: SAGINAW
NOAA chart: 14867

community: SAGINAW
county: SAGINAW
state: MICHIGAN
Township/Range T.12N R.04E
section: 24

HORIZONTAL

datum: NAD83
lat: 43° 25'40.44591" N
lon: 83° 56'33.46051" W

Y: 0.00 m (N)
X: 0.00 m (E)

Y: 702,879.28 ft (US) N
X: 13,235,976.89 ft (US) E

state: MICHIGAN
projection: LAMBERT
zone: S
code: 2113

HORIZONTAL ORIGIN

agency: USACE
order:
date: 03/23/93
method: GPS
set by: D. HENRY

Point Source:

JONAS 1932
PARRISH

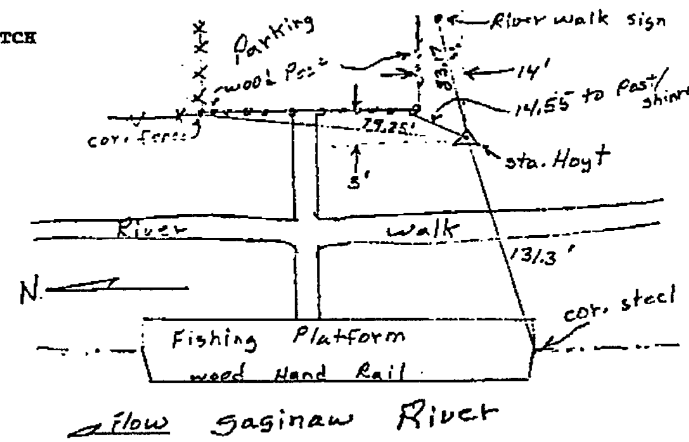
MOST RECENT RECOVERY
03/23/93 NEW

VERTICAL	feet	meters
IGLD 1955:	0.000	0.000
IGLD 1985:	0.000	0.000
NAVD 1988:	0.000	0.000
NGVD 1929:	0.000	0.000
pt. source:		
geoid. hgt:	0.000	0.000

PROPERTY OWNER
firm:
P.O.C. RIVER WALK
telephone:
access: car, boat

DESCRIPTION
STATION HOYT IS A BRASS DISK SET IN A SIX-INCH-DIA. CONCRETE MONUMENT FLUSH WITH THE GROUND. STATION IS 14.55 FT. SOUTHWEST OF POST AT THE SOUTHWEST CORNER OF THE PARKING LOT. STATION IS ON THE EAST SIDE OF THE SAGINAW RIVER BETWEEN THOMPSON ST. AND HOYT ST. AND ON THE WEST SIDE OF SOUTH WATER ST. TO REACH STATION FROM I-675, TAKE WASHINGTON ST. SOUTH TO HOYT ST., TURN RIGHT ON HOYT AND GO TO SOUTH WATER ST.. TURN RIGHT ON SOUTH WATER ST. AND PARKING LOT FOR RIVER WALK IS ON YOUR LEFT SIDE.

SKETCH



Ref # SAG-0613 **SURVEY CONTROL DATA** Desig: HOYT

Office of Record: Saginaw Area Office

Printed on 11/04/93

Figure D-27. Descriptions of Stations Hoyt, Wickes, Eward, Rust, Holland, and Genesee (Sheet 1 of 6)

U.S. ARMY ENGINEER DISTRICT - DETROIT

GENERAL INFORMATION

designation: WICKES
reference no. SAG-0610

project: SAGINAW RIVER
channel/reach: UPPER
sheet no.
USGS Quad: SAGINAW
NOAA chart: 14867

community: SAGINAW
county: SAGINAW
state: MICHIGAN
Township/Range T.12N R.04E
section: 25

HORIZONTAL

datum: NAD83
lat: 43° 23'18.39093" N
lon: 83° 57'49.94860" W

Y: 0.00 m (N)
X: 0.00 m (E)

Y: 688,469.29 ft (US) N
X: 13,230,401.67 ft (US) E

state: MICHIGAN
projection: LAMBERT
zone: S
code: 2113

HORIZONTAL ORIGIN

agency: USACE
order:
date: 03/23/93
method: GPS
set by: D. HENRY

Point Source:

JONAS 1932
PARRISH

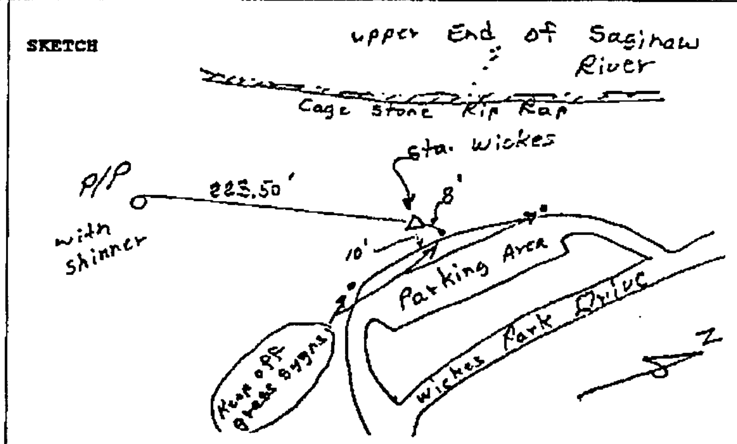
MOST RECENT RECOVERY
03/23/93 NEW

VERTICAL	**feet**	**meters**
IGLD 1955:	0.000	0.000
IGLD 1985:	0.000	0.000
NAVD 1988:	0.000	0.000
NGVD 1929:	0.000	0.000
pt. source:		
geoid. hgt:	0.000	0.000

PROPERTY OWNER
firm:
P.O.C. WICKS PARK
telephone:
access: car, boat

DESCRIPTION
STATION WICKES IS AN ALUM. DISK IN A SIX-INCH-DIA. CONCRETE MONUMENT FLUSH WITH THE GROUND SURFACE. STATION IS AT THE VERY UPPER END OF THE SAGINAW RIVER ON THE EAST SIDE IN WICKS PARK. TO REACH STATION FROM THE INTERSECTION OF M-13 (WASHINGTON) AND I-675, GO SOUTH ON M-13 UNTIL YOU REACH WICKS PARK DRIVE, TURN RIGHT AND GO TO THE RIVER. STATION IS AT THE PARKING AREA WHERE WICKS PARK DRIVE TURNS TO THE NORTH.

SKETCH



Ref #. **SAG-0610** **SURVEY CONTROL DATA** Desig: **WICKES**

Office of Record: Saginaw Area Office — Printed on 11/04/93

Figure D-27. (Sheet 2 of 6)

U.S. ARMY ENGINEER DISTRICT - DETROIT

GENERAL INFORMATION

designation: EWALD
reference no. SAG-0611

project: SAGINAW RIVER
channel/reach: UPPER
sheet no.
USGS Quad: SAGINAW
NOAA chart: 14867

community: SAGINAW
county: SAGINAW
state: MICHIGAN
Township/Range T.12N R.04E
section: 26

HORIZONTAL

datum: NAD83
lat: 43° 24'57.45612" N
lon: 83° 57'44.52799" W

Y: 0.00 m (N)
X: 0.00 m (E)

Y: 698,500.99 ft (US) N
X: 13,230,753.75 ft (US) E

state: MICHIGAN
projection: LAMBERT
zone: S
code: 2113

HORIZONTAL ORIGIN

agency: USACE
order:
date: 03/23/93
method: GPS
set by: D. HENRY

Point Source:

JONAS 1932
PARRISH

MOST RECENT RECOVERY
03/23/93 NEW

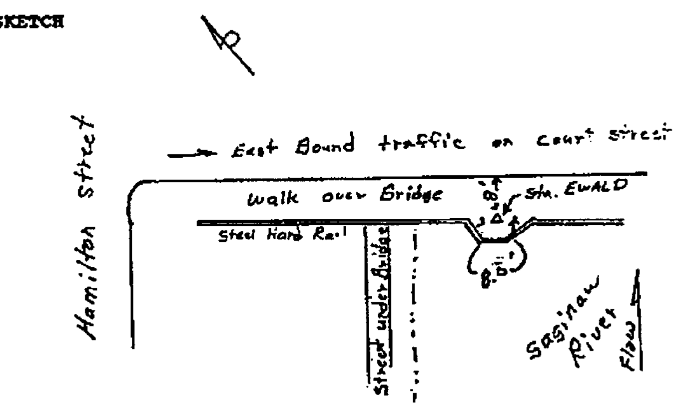
VERTICAL

	feet	meters
IGLD 1955:	0.000	0.000
IGLD 1985:	0.000	0.000
NAVD 1988:	0.000	0.000
NGVD 1929:	0.000	0.000
pt. source:		
geoid. hgt:	0.000	0.000

PROPERTY OWNER
firm:
P.O.C. ON BRIDGE
telephone:
access: , hike

DESCRIPTION
STATION EWALD IS A BRASS DISK SET INTO A CONCRETE SIDEWALK ON THE UPSTREAM SIDE OF THE COURT STREET BRIDGE OVER THE SAGINAW RIVER IN THE CITY OF SAGINAW. STATION IS 475 FT. (+-) WEST TO SOUTH HAMILTON STREET FROM STATION. STATION IS AT THE FIRST OBSERVATION PLATFORM FROM THE WEST SIDE OF THE BRIDGE. TO REACH COURT STREET BRIDGE FROM I-675, TAKE M-13 (WASHINGTON) SOUTH TO RUST DRIVE, TURN RIGHT AND IT TAKES YOU ACROSS THE COURT STREET BRIDGE AND STREET TURNS INTO COURT STREET.

SKETCH



Ref # **SAG-0611** **SURVEY CONTROL DATA** Desig: **EWALD**

Office of Record: Saginaw Area Office

Printed on 11/04/93

Figure D-27. (Sheet 3 of 6)

U.S. ARMY ENGINEER DISTRICT - DETROIT

GENERAL INFORMATION

designation: RUST
reference no. SAG-0612

project: SAGINAW RIVER
channel/reach: UPPER
sheet no.
USGS Quad: SAGINAW
NOAA chart: 14867

community: SAGINAW
county: SAGINAW
state: MICHIGAN
Township/Range T.12N R.04E
section: 26

HORIZONTAL

datum: NAD83
lat: 43° 24'30.42050" N
lon: 83° 58' 1.20657" W

Y: 0.00 m (N)
X: 0.00 m (E)

Y: 695,757.90 ft (US) N
X: 13,229,535.80 ft (US) E

state: MICHIGAN
projection: LAMBERT
zone: S
code: 2113

HORIZONTAL ORIGIN

agency: USACE
order:
date: 03/23/93
method: GPS
set by: D. HENRY

Point Source:

JONAS 1932
PARRISH

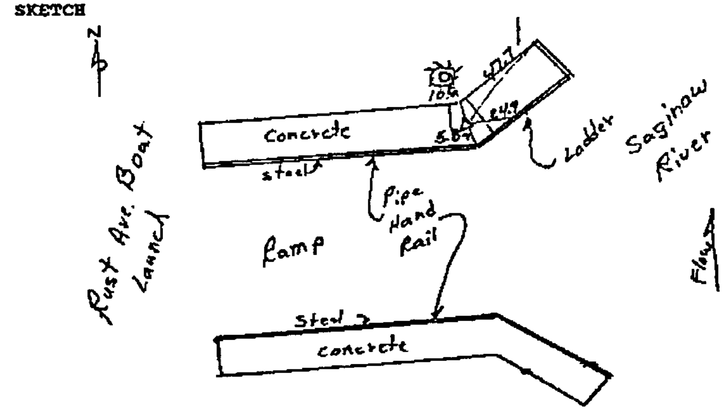
MOST RECENT RECOVERY
03/23/93 NEW

VERTICAL	feet	meters
IGLD 1955:	0.000	0.000
IGLD 1985:	0.000	0.000
NAVD 1988:	0.000	0.000
NGVD 1929:	0.000	0.000
pt. source:		
geoid. hgt:	0.000	0.000

PROPERTY OWNER
firm: SAGINAW
P.O.C. BOAT LAUNCH
telephone:
access: car, boat

DESCRIPTION
STATION IS A BRASS DISK SET IN CONCRETE ON THE NORTH SIDE OF A BOAT LAUNCH RAMP (RUST AVE. BOAT LAUNCH) OWNED BY THE CITY OF SAGINAW. TO REACH STATION FROM THE RUST STREET BRIDGE (M-46) OVER THE SAGINAW RIVER, TAKE SOUTH HAMILTON SOUTH TO LEE STREET, GO EAST TO RIVER AND RUST AVE. BOAT LAUNCH IS AT THE END OF THE STREET. NOTE: THERE ARE TWO SIGNS DIRECTING YOU TO THE BOAT LAUNCH, LEE ST. & SOUTH HAMILTON, AND ONE NEAR THE BRIDGE ON THE WEST SIDE OF THE RIVER.

SKETCH



Ref # **SAG-0612** **SURVEY CONTROL DATA** Desig: **RUST**

Office of Record: Saginaw Area Office

Printed on 11/04/93

Figure D-27. (Sheet 4 of 6)

U.S. ARMY ENGINEER DISTRICT - DETROIT

GENERAL INFORMATION

designation: HOLLAND
reference no. SAG-0608

project: SAGINAW RIVER
channel/reach: UPPER
sheet no.
USGS Quad: SAGINAW
NOAA chart: 14867

community: SAGINAW
county: SAGINAW
state: MICHIGAN
Township/Range T.12N R.04E
section: 25

HORIZONTAL

datum: NAD83
lat: 43° 25'14.91718" N
lon: 83° 57' 4.12068" W

Y: 0.00 m (N)
X: 0.00 m (E)

Y: 700,283.35 ft (US) N
X: 13,233,727.24 ft (US) E

state: MICHIGAN
projection: LAMBERT
zone: S
code: 2113

HORIZONTAL ORIGIN

agency: USACE
order:
date: 03/23/93
method: GPS
set by: D.HENRY

Point Source:

JONAS 1932
PARRISH

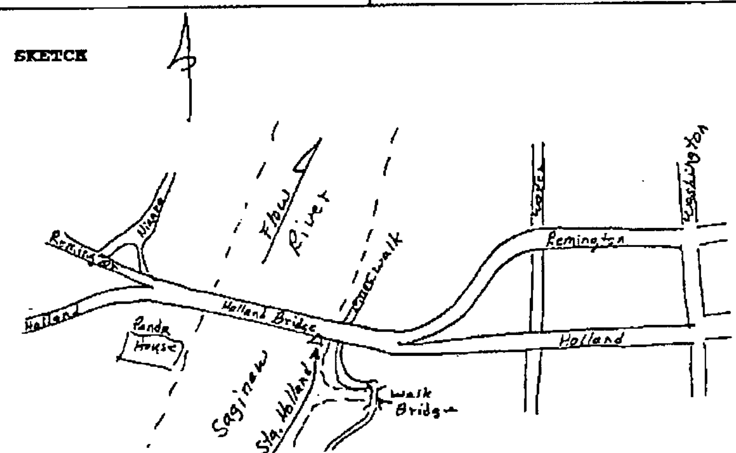
MOST RECENT RECOVERY
03/23/93 NEW

VERTICAL	feet	meters
IGLD 1955:	0.000	0.000
IGLD 1985:	0.000	0.000
NAVD 1988:	0.000	0.000
NGVD 1929:	0.000	0.000
pt. source:		
geoid. hgt:	0.000	0.000

PROPERTY OWNER
firm:
P.O.C.
telephone:
access: , hike

DESCRIPTION
STATION HOLLAND IS A STANDARD BRASS DISK SET INTO A CONCRETE WALK ON THE UPSTREAM SIDE OF THE HOLLAND AVE. BRIDGE OVER THE SAGINAW RIVER. STATION IS ON THE EAST-BOUND SIDE OF SAID FOUR-LANE BRIDGE. REMINGTON ST. GOES TO THE WEST ACROSS THE BRIDGE AND HOLLAND ST. GOES TO THE EAST ACROSS THE BRIDGE.

SKETCH



Ref # **SAG-0608** **SURVEY CONTROL DATA** *Desig:* **HOLLAND**

Office of Record: Saginaw Area Office
Printed on 11/04/93

Figure D-27. (Sheet 5 of 6)

U.S. ARMY ENGINEER DISTRICT - DETROIT

GENERAL INFORMATION

designation: GENESEE
reference no. SAG-0609

project: SAGINAW RIVER
channel/reach: UPPER
sheet no.
USGS Quad: SAGINAW
NOAA chart: 14867

community: SAGINAW
county: SAGINAW
state: MICHIGAN
Township/Range T.11N R.04E
section: 2

HORIZONTAL

datum: NAD83
lat: 43° 26' 1.64599" N
lon: 83° 56'34.06378" W

Y: 0.00 m (N)
X: 0.00 m (E)

Y: 705,025.46 ft (US) N
X: 13,235,921.57 ft (US) E

state: MICHIGAN
projection: LAMBERT
zone: S
code: 2113

HORIZONTAL ORIGIN

agency: USACE
order:
date: 03/23/93
method: GPS
set by: D. HENRY

Point Source:

JONAS 1932
PARRISH

MOST RECENT RECOVERY
03/23/93 NEW

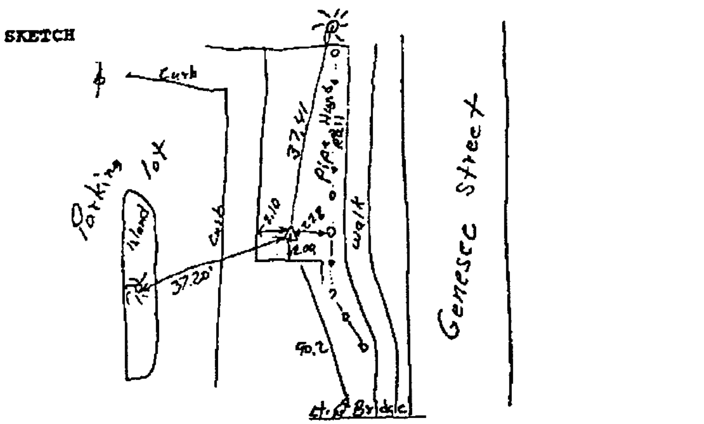
VERTICAL	feet	meters
IGLD 1955:	0.000	0.000
IGLD 1985:	0.000	0.000
NAVD 1988:	0.000	0.000
NGVD 1929:	0.000	0.000
pt. source:		
geoid. hgt:	0.000	0.000

PROPERTY OWNER
firm:
P.O.C.
telephone:
access: car, boat

DESCRIPTION
STATION GENESEE IS A STANDARD BRASS DISK SET IN CONCRETE AT THE SOUTHEAST CORNER OF THE INTERSECTION OF WEST GENESEE & NORTH NIAGARA. STATION IS 100 FT. WEST OF THE GENESEE STREET BRIDGE OVER THE SAGINAW RIVER AND 50 FT. EAST OF NORTH NIAGARA. STATION IS ON CONCRETE THAT IS 2 FT. ABOVE THE PARKING LOT AND ON THE SOUTH SIDE OF THE HANDRAIL OF THE SIDEWALK. STATION IS 2.1 FT. NORTH OF CONCRETE EDGE, 2.09 FT. WEST OF CONCRETE EDGE, 2.28 FT. SOUTH OF HANDRAIL, AND 37.41 FT. EAST-SOUTHEAST OF LIGHTPOST AT STREET CORNER.

TO REACH STATION FROM THE INTERSECTION OF M-13 (WASHINGTON) AND I-675, GO SOUTH ON M-13 TO GENESEE AND TURN RIGHT, GO ACROSS THE RIVER TILL YOU COME TO NIAGARA ST.. STATION IS AT THIS INTERSECTION.

SKETCH



Ref # **SAG-0609** **SURVEY CONTROL DATA** Desig: **GENESEE**

Office of Record: Saginaw Area Office *Printed on 11/04/93*

Figure D-27. (Sheet 6 of 6)

Appendix E
Horn Lake, Mississippi, Stop-and-Go GPS Survey

E-1. General

In geographical areas with minimal obstruction of the sky, such as farming areas, along levees and open roads, stop-and-go GPS surveying can be a very effective and efficient method of establishing 2D and/or 3D project control. Stop-and-go surveying can be used to establish horizontal control for topographic and hydrographic surveys as well as 3D ground control for photogrammetric surveys.

E-2. Project Description

This example survey was conducted by the Memphis District in the vicinity of Horn Lake, Mississippi, approximately 15 miles south of downtown Memphis, Tennessee. A diagram of the project area is shown in Figure E-1. The project consisted of establishing 3D positions on a total of 23 photo control points.

E-3. Planning Phase

An initial search was performed to locate existing NGRS and USACE horizontal and vertical control within a 10-km radius of the center of the project area. It is important to note that the marks chosen to be occupied by

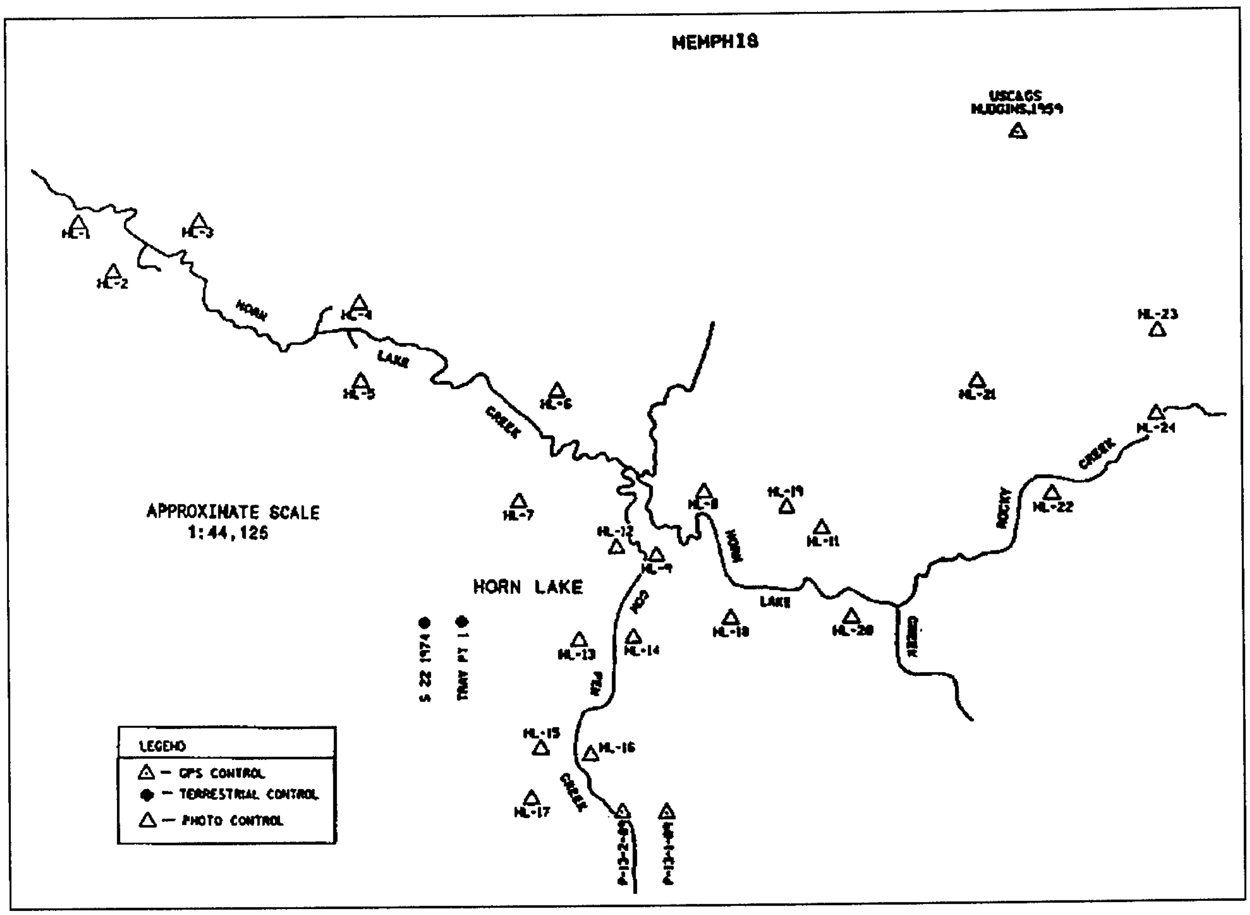


Figure E-1. Horn Lake Project diagram

the reference receiver(s) should be totally unobstructed. A momentary loss of lock (cycle slip) on one or more satellites by the reference receiver(s) could make it impossible to process some or all of the data obtained by the roving receiver(s).

a. Three NGRS horizontal and/or 3D control marks were recovered near the project area; however, due to obstructions at two of the sites, only the 3D mark USC&GS HUDGINS 1959 was suitable as a reference station. Preplanning analysis indicated a minimum of two reference stations were needed to economically obtain the required number of independent baseline measurements to each photo control point. Therefore, to meet this requirement, a pair of intervisible Type A monuments, as defined in EM 1110-1-1002, were installed near the southern limit of the project area with one of the sites (P-13-2-89) being totally free of obstructions greater than 15 degrees above the horizon. Initially, a static GPS survey was performed to establish horizontal positions on the two Type A monuments. A diagram of the initial horizontal control survey is shown in Figure E-2. Refer to the example surveys in Appendix D for details on performing a static horizontal control survey. Figure E-3 shows a partial output of the GEOLAB minimally constrained adjustment of the static baselines observed. A review of the GEOLAB adjustment output reveals the following:

(1) As shown the 2D and 1D station major semi-axis and minor semi-axis are at or less than the few-centimeter level.

(2) The 2D and 1D relative error ellipses between survey points are at or less than the few-centimeter level.

(3) The estimated variance factor in the statistics summary is low (close to a value of 1). Further analysis of the GEOLAB output in Figure E-3 indicates that the adjustment is very acceptable and that the adjusted positions of the two Type A monuments will be more than adequate for use as horizonal control for the stop-and-go survey. Reference stations USC&GS HUDGINS 1959 and P-13-2-89 were chosen because of their unobstructed view of the sky and also their location relative to the project area.

b. One NGRS vertical control mark and three USACE temporary benchmarks (TBM's) were recovered within the project area. The NGRS vertical control mark was 100 percent obstruction free and was thus included within the stop-and-go survey. However, due to obstructions at all three of the TBM's, it was decided not to include these marks within the GPS survey. Instead, differential levels were run from the TBM's to the nearest

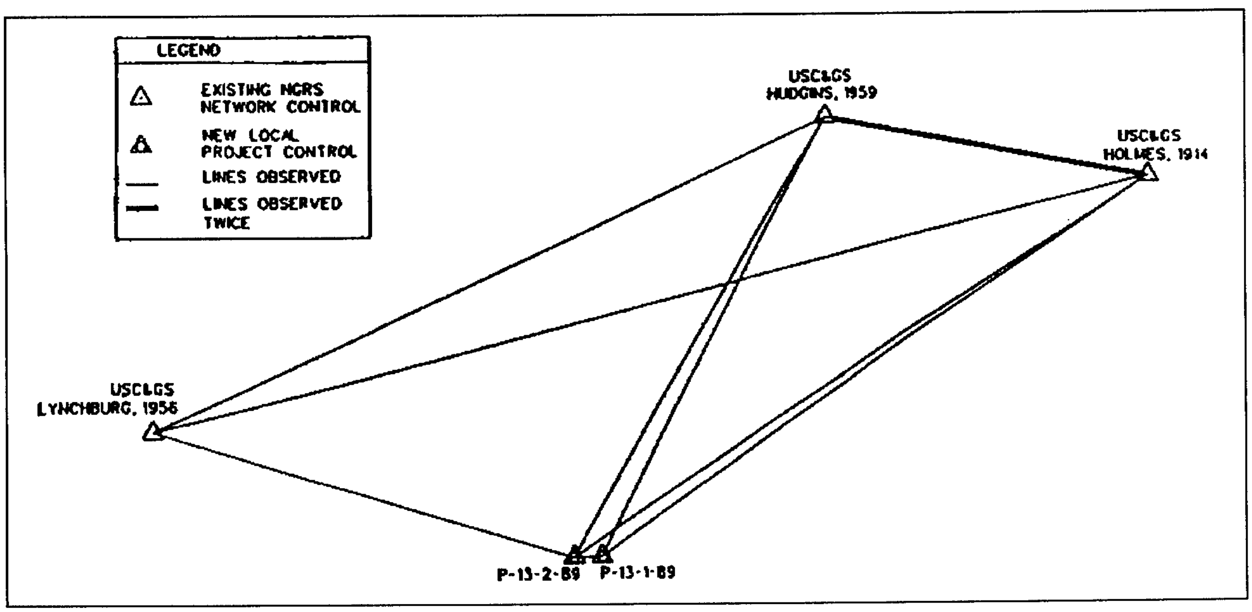


Figure E-2. Initial horizontal control survey

```
--------------------------------------------------------------------------------
              U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
               GPS #7 - HORN LAKE CREEK AERIAL PHOTO CONTROL
A= 6378137.000 B= 6356752.314 XO=        0.000 YO=        0.000 ZO=        0.000
--------------------------------------------------------------------------------
ELLIPSE:

2-D AND 1-D STATION CONFIDENCE REGIONS ( 95.000 %):
---------------------------------------------------------
IDENT.     MAJOR SEMI-AXIS  MINOR SEMI-AXIS  AZ(MAJ)        VERTICAL
-------- ---------------- ---------------- -------- ---------------
4098              0.0170           0.0116   119.60          0.0231
3095              0.0154           0.0092   118.54          0.0189
1096              0.0338           0.0136   116.46          0.0333
4097              0.0174           0.0123   118.20          0.0247

--------------------------------------------------------------------------------
GeoLab - V1.91S, (C) 1985/86/87/88/89 BitWise Ideas Inc. [103208976]  Page   14


--------------------------------------------------------------------------------
              U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
               GPS #7 - HORN LAKE CREEK AERIAL PHOTO CONTROL
A= 6378137.000 B= 6356752.314 XO=        0.000 YO=        0.000 ZO=        0.000
--------------------------------------------------------------------------------
ELLIPSE:

2-D AND 1-D RELATIVE STATION CONFIDENCE REGIONS ( 95.000 %):
---------------------------------------------------------------
FROM     TO        MAJ.SEMI MIN.SEMI AZ(MAJ) VERTICAL SPATIAL DIST.   PRECISION
-------- -------- -------- -------- ------- -------- ------------- -----------
3094     1096       0.0338   0.0136  116.46   0.0333    13216.8982   2.559 PPM
3094     4097       0.0174   0.0123  118.20   0.0247     8561.2490   2.029 PPM
3094     4098       0.0170   0.0116  119.60   0.0231     8872.2474   1.912 PPM
3094     3095       0.0154   0.0092  118.54   0.0189     4254.4135   3.612 PPM
4098     1096       0.0309   0.0101  116.01   0.0274     5576.4108   5.539 PPM
4098     4097       0.0055   0.0045   84.37   0.0104      366.6958  14.958 PPM
4098     3095       0.0100   0.0085  135.51   0.0171     6444.1941   1.545 PPM
3095     1096       0.0316   0.0117  116.41   0.0300     9503.6545   3.321 PPM
3095     4097       0.0107   0.0095  125.96   0.0194     6257.9676   1.717 PPM

ELLIPSE successfully completed.
12:20:35 - Monday, July 10, 1989

--------------------------------------------------------------------------------
GeoLab - V1.91S, (C) 1985/86/87/88/89 BitWise Ideas Inc. [103208976]  Page   15
```

Figure E-3. GEOLAB adjustment output (Continued)

```
U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
GPS #7 - HORN LAKE CREEK AERIAL PHOTO CONTROL
A=  6378137.000 B=  6356752.314 XO=        0.000 YO=        0.000 ZO=        0.000

RESID:
```

STATISTICS SUMMARY

Residual Critical Value Type	Tau Max
Residual Critical Value	3.1459
Convergence Criterion	0.001000
Final Iteration Counter Value	2
Confidence Level Used	95.0000
Number of Flagged Residuals	0
Estimated Variance Factor	1.3100
Number of Degrees of Freedom	27

```
Chi-Square Test on the Variance Factor:

8.1887e-001  <  1.0000  <  2.4271e+000  ?

THE TEST PASSES.

RESID successfully completed.

GeoLab - V1.91S, (C) 1985/86/87/88/89 BitWise Ideas Inc. [103208976]  Page   12
```

Figure E-3. (Concluded)

photo control point. The four points circled in Figure E-4 had an established orthometric height. These heights were used to control the vertical adjustment of the GPS observations. This will be discussed further under the section on adjustments.

c. The aerial photography was completed and photo control points were subsequently selected from observable physical features. The GPS survey party had to locate the points from the photos and monument each on the ground. Obstruction limits at each point were noted during monumentation. After all 23 points were established, further analysis indicated that three of the points, HL-2, HL-5, and HL-7 could not be occupied because of extensive obstructions or no vehicular access. Terrestrial traversing was performed to HL-2 and HL-5 using HL-1 and HL-3 as control and to HL-7 using S 22 1974 and Trav Pt 1 as control. The traverse computations were performed subsequent to the final constrained least squares adjustment of the baselines observed during the stop-and-go survey.

E-4. GPS Field Observations

Four SPS (or C/A) code GPS receivers, tracking the carrier phase, were used for the survey. When performing a stop-and-go survey, it is required to maintain lock on at least four satellites. It is recommended that observation-times be scheduled when at least five satellites are visible, so that if lock is lost on one satellite, the survey can continue. All GPS field observations, both static and stop-and-go, were recorded on 28 and 29 June 1989 (days 179 and 180). The reference receiver at HUDGINS was set up to continually record data each day and left unmanned due to its secure location. The reference receiver at P-13-2-89 had one operator monitoring it and there were two personnel per roving receiver: one to drive the vehicle and operate the receiver and the other to position the antenna over the mark. Communication between operators was by two-way radio.

a. The antennas at the reference stations were mounted on a tripod using an optical plummet tribrach with an 8-minute bulls-eye level. The antenna for each roving receiver was mounted on a fixed-height range pole with a 10-minute bulls-eye level supported by a bipod. The antenna, range pole, and bipod were secured to the vehicle by a removable mobile rack shown in Figure E-5. Figure E-6 shows the setup of the antenna, range pole and bipod.

b. A satellite visibility chart was plotted for day 179 and is shown in Figure E-7. Static measurements were recorded for the first two sessions and the data used to establish horizontal positions on the two Type A monuments. Refer to Figure E-2 for a graphical representation of the baselines observed during sessions 1 and 2. The remainder of the five-satellite window for day 179 was used to record stop-and-go data. The observation schedule developed for day 179 is shown in Figure E-8. The upper portion of the schedule includes the ID number, the name and the position (exact if known, scaled if not) for each station included within the survey. Note that the photo control points were assigned a 5000 series ID. Chapter 8 of this manual discusses recommended conventions for assigning station ID numbers. It recommends a 9000 series number for temporary 3D control. The bottom portion of the schedule includes the date and day of the year in which observations are to be recorded, where each receiver will be for each session, when to start and stop each session (local time), and which satellites to observe.

c. Stop-and-go observations were recorded during the third session on day 179 and during the entire five-satellite window on day 180. During the third session of day 179, both roving receivers were initialized to both of the reference receivers by recording static data for approximately one hour. This method is also referred to as occupying a known baseline, since after post-processing the static data and the data are accepted according to the criteria in this manual, the baseline becomes known. It is important to note that this method requires a sufficient amount of data be collected to ensure that the integer cycle ambiguities are resolved in the baseline solution. Once the integer cycle ambiguity is resolved for a satellite, it remains constant as long as lock is maintained. At the moment lock is lost on a satellite, its integer cycle ambiguity becomes an unknown value and thus again requires resolution. Initially resolving the ambiguities and maintaining lock on at least four satellites is the key to stop-and-go surveying. If lock is not maintained on at least four satellites during a survey, the ambiguities for at least four satellites will need to be resolved again. This can be done during a survey by returning to the last occupied point, which becomes a known baseline after postprocessing. If this method is not practical or desirable, the survey should be stopped at the point of losing lock on at least four satellites and a new survey started. The new survey may be initialized either by recording approximately an hour of static data at a point which has not already been occupied, or by recording a few minutes of data at a point which has been previously occupied. When using the second method, the integer cycle ambiguities for the baselines from both reference receivers to the

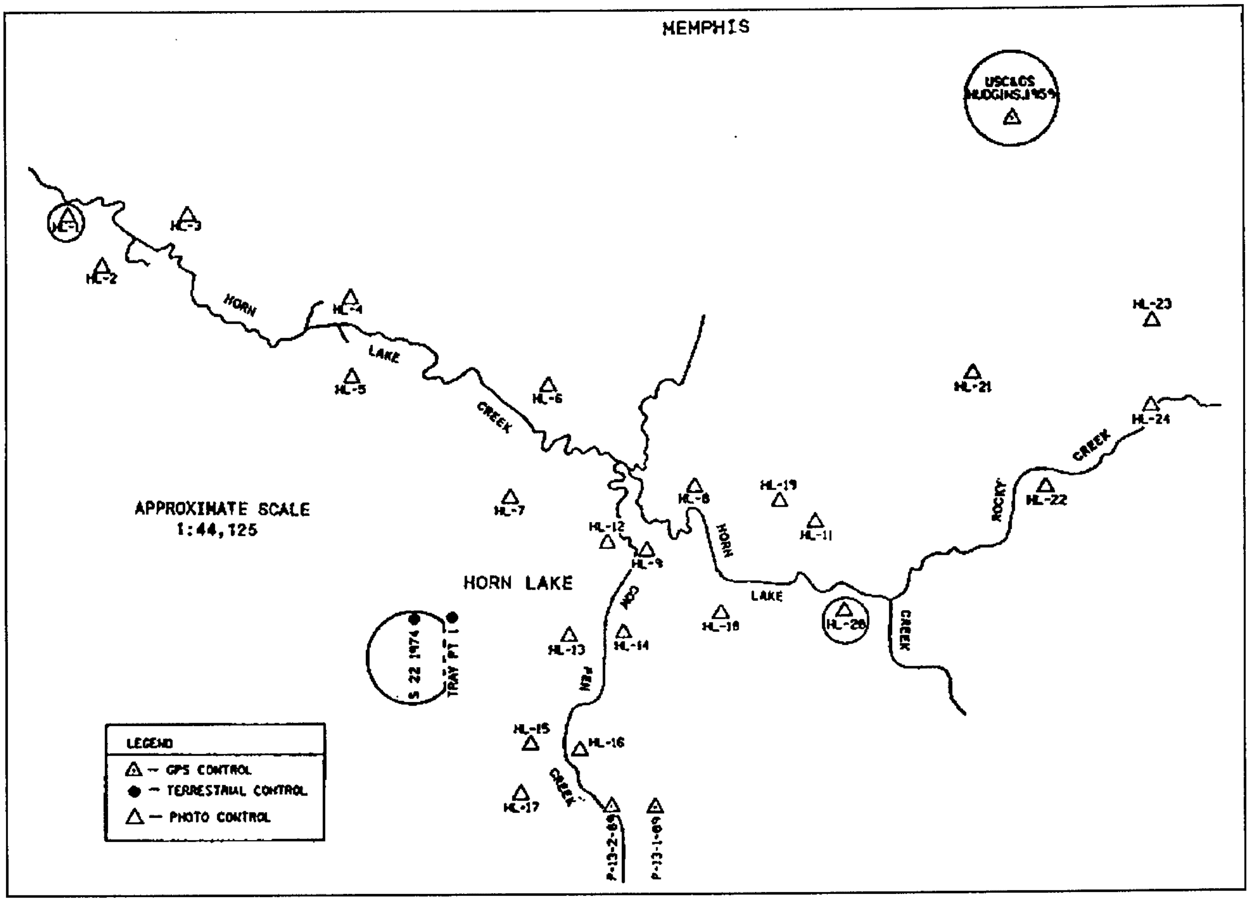


Figure E-4. Vertical project control

Figure E-5. Removable vehicle rack

Figure E-6. Antenna-range pole-bipod setup

point must have been resolved. Figures E-9 and E-10 show the baselines for which the integer cycle ambiguities were resolved by collecting static data for approximately one hour by roving receivers 1 and 2, respectively.

d. After initializing the stop-and-go survey, the rovers began to travel from point to point, collecting approximately 1.25 minutes of data at each point. This manual recommends data collection of at least 1.5 min at each point. Experience has shown this value should be used as a minimum and, depending on the length of the baselines observed and the accuracy required for the survey, observation times of up to 10 min may be necessary to ensure the desired results are obtained. A data logging sheet such as that shown in Chapter 8 was completed for each reference receiver. For each roving receiver, a stop-and-go field form as shown in Figure E-11 was completed. Figure E-12 shows a field form completed for roving receiver 1 on day 179. The paths taken by each of the rovers on days 179 and 180 can be graphically seen in Figures E-9 and/or E-10. The data collected for the initialization of the survey as well as the data collected at each subsequent point by rover 1 were recorded in one data file. It is recommended that static observations be recorded in a separate file from the stop-and-go data to conform to batch processing methods used in some manufacturer's software. This will be discussed further under the section on post-processing. Referring to Figure E-12, the following is a recommended scheme for recording the data such that a batch processing mode may be utilized.

(1) Start static survey at 22:04 occupying station 4097. Stop static survey at 23:00.

(2) After resetting the antenna over station 4097, start a stop-and-go survey and collect data at 4097 for approximately ten minutes.

(3) Travel to each subsequent point and collect data for at least 1.5 minutes.

(4) Upon losing lock travelling to station 5208, stop the stop-and-go survey.

(5) Continue to 5208, position antenna over mark and start a static survey at approximately 00:42.

(6) Stop the static survey at 01:45, which was very near the end of the four satellite window for day 179.

If additional time had been available in which five satellites were above 15 degrees, another stop-and-go survey could have been started and continued from 5208 to additional points subsequent to the static data collection.

E-5. Post-processing Stop-and-Go Data

At the end of each day's observations, all data were downloaded from the receivers to a portable 386 computer. All processing times quoted in this example are using a 386 computer with a math coprocessor with a 20-MHz clock processing speed. Using a computer with slower clock speeds will significantly increase processing time of all types of GPS data, not only stop-and-go. A review of all field data logging sheets for completeness and correctness was performed after downloading the data. Trimble's Trimvec-Plus survey software was used for all post-processing in this case.

a. First, all data collected in the static survey mode were post-processed and the quality of the solutions reviewed. Processed baselines from sessions 1 and 2 of day 179 were used to create a network in GEOLAB and adjusted separately from the photo control. The results of this adjustment have been discussed in paragraph E-3. Since the stop-and-go survey was initialized with known baselines, the dX, dY, and dZ values for the known baselines were required prior to processing the stop-and-go data. These values were obtained from the solution output of the static observations. Figures E-13 and E-14 show the solution summaries for the baselines from each of the reference receivers to roving receiver 1. Notice that the integers were found for each baseline and that the

Table of Azimuth, Elevation and Time for HORNLAKE
Date : 28 Jun 1989
Time : 15:00 -> 21:00
Cut-off Elevation : 12°
Latitude : 34° 58' 00" N
Longitude : 90° 02' 00" W
Zone : - 5:00

Table of Azimuth, Elevation and Time for HORNLAKE
28 Jun 1989
15:00 -> 21:00
Elevation : 12°
Latitude : 34° 58' 00" N
Longitude : 90° 02' 00" W
Zone : - 5:00

Time	Satellite 3		Satellite 4		Satellite 8		Satellite 9		Satellite 11		Satellite 12		Satellite 13		Satellite 14		Satellite --		Satellite --	
	AZ	EL	AZ	EL	AZ	EL	AZ	EL	AZ	EL	AZ	EL	AZ	EL	AZ	EL	AZ	EL	AZ	EL
15:00	..	..	331°	43°	230°	67°	..	..	221°	27°	..	..	..	..	..	..				
15:10	..	..	331°	48°	241°	71°	..	..	225°	31°	..	..	..	..	..	..				
15:20	..	..	331°	53°	257°	74°	..	..	229°	35°	..	..	..	..	..	..				
15:30	..	..	331°	58°	278°	74°	..	..	233°	39°	..	..	..	..	..	..	Start	4	SV	Window
15:40	..	..	329°	63°	302°	76°	327°	14°	239°	42°	..	..	..	..	..	..				
15:50	..	..	325°	68°	322°	74°	327°	19°	244°	46°	..	..	..	..	..	..				
16:00	..	..	317°	73°	337°	71°	327°	23°	251°	49°	..	..	..	..	..	..				
16:10	..	..	303°	77°	348°	67°	327°	28°	258°	52°	..	..	..	..	..	..				
16:20	..	..	277°	79°	357°	64°	326°	32°	265°	54°	..	..	..	..	..	..				
16:30	..	..	246°	79°	4°	60°	324°	37°	274°	56°	..	..	243°	13°	..	..	Start	5	SV	Window
16:40	..	..	224°	75°	10°	56°	321°	41°	283°	58°	..	..	247°	16°	..	..				
16:50	..	..	212°	71°	15°	52°	318°	45°	293°	59°	..	..	251°	19°	..	..				
17:00	..	..	205°	66°	20°	49°	313°	49°	303°	59°	..	..	256°	22°	..	..				
17:10	..	..	201°	60°	25°	45°	306°	53°	313°	59°	330°	13°	260°	24°	..	..				
17:20	..	..	199°	55°	29°	42°	299°	56°	322°	59°	328°	17°	265°	27°	..	..				
17:30	..	..	197°	49°	33°	38°	289°	57°	332°	59°	326°	21°	270°	29°	143°	14°				
17:40	..	..	195°	44°	37°	35°	279°	58°	341°	58°	324°	25°	275°	32°	140°	18°				
17:50	..	..	194°	38°	42°	32°	269°	58°	350°	56°	320°	28°	281°	34°	137°	21°				
18:00	..	..	193°	33°	46°	29°	259°	56°	358°	55°	317°	31°	286°	36°	134°	24°				
18:10	..	..	192°	28°	50°	26°	251°	54°	6°	53°	312°	34°	292°	38°	130°	28°				
18:20	..	..	192°	23°	54°	23°	243°	50°	13°	52°	307°	36°	298°	40°	127°	31°				
18:30	..	..	191°	18°	58°	21°	237°	47°	20°	50°	302°	38°	304°	42°	122°	34°				
18:40	..	..	190°	14°	62°	18°	232°	42°	27°	48°	296°	39°	310°	44°	118°	37°				
18:50	..	..	..	..	66°	16°	228°	38°	33°	46°	289°	39°	317°	46°	113°	40°				
19:00	284°	14°	..	..	70°	13°	225°	34°	39°	44°	283°	39°	323°	47°	107°	42°				
19:10	288°	16°	..	..	..	..	221°	29°	46°	42°	277°	38°	330°	49°	101°	44°				
19:20	293°	18°	..	..	..	..	219°	25°	51°	40°	271°	36°	337°	50°	94°	45°				
19:30	297°	21°	..	..	..	..	216°	21°	57°	38°	265°	34°	345°	52°	87°	46°				
19:40	301°	23°	..	..	..	..	214°	16°	63°	36°	260°	31°	353°	53°	80°	46°				
19:50	305°	26°	..	..	..	..	212°	12°	68°	34°	255°	28°	1°	54°	74°	45°				
20:00	310°	28°	..	..	..	..	..	..	74°	32°	251°	25°	9°	55°	67°	44°				
20:10	314°	31°	..	..	..	..	..	..	79°	29°	247°	22°	18°	56°	62°	42°				
20:20	319°	34°	..	..	..	..	..	..	84°	27°	243°	18°	27°	56°	57°	39°				
20:30	323°	37°	..	..	..	..	..	..	89°	24°	239°	15°	36°	57°	53°	36°	Stop	5	SV	Window
20:40	328°	40°	..	..	..	..	..	..	94°	22°	..	..	45°	56°	49°	33°				
20:50	332°	43°	..	..	..	..	..	..	98°	19°	..	..	54°	56°	47°	29°	Stop	4	SV	Window
21:00	337°	47°	..	..	..	..	..	..	103°	16°	..	..	63°	55°	44°	26°				

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Figure E-7. Satellite visibility chart

GPS PROJECT No. 7-K
HORN LAKE CREEK PHOTO CONTROL Stop and Go SURVEY
HORN LAKE, MISSISSIPPI

STATION NUMBER	STATION NAME	LATITUDE	LONGITUDE	HEIGHT
3094	HOLMES 1914	34-59-27.00296	89-57-22.44228	123.897
3095	HUDGINS 1959	34-59-52.56136	90-00-07.30092	106.019
1096	LYNCHBERG 1956	34-57-45.46270	90-05-48.68871	94.000
4097	P-13-1-89	34-56-54.00000	90-02-03.00000	91.000
4098	P-13-2-89	34-56-54.00000	90-02-18.00000	84.000
2099	S 22 1974	34-57-45.00000	90-03-18.00000	80.902
5201	HL-1	34-59-30	90-05-05	74.000
5202	HL-2	34-59-18	90-05-00	75.000
5203	HL-3	34-59-30	90-04-30	72.000
5204	HL-4	34-59-13	90-03-38	75.000
5205	HL-5	34-58-40	90-03-38	75.000
5206	HL-6	34-58-45	90-02-35	79.000
5207	HL-7	34-58-15	90-02-45	79.000
5208	HL-8	34-58-20	90-01-47	80.000
5209	HL-9	34-58-02	90-02-02	78.000
5211	HL-11	34-58-10	90-01-08	81.000
5212	HL-12	34-58-05	90-02-17	80.000
5213	HL-13	34-57-40	90-02-28	80.000
5214	HL-14	34-57-38	90-02-20	80.000
5215	HL-15	34-57-12	90-02-40	84.000
5216	HL-16	34-57-10	90-02-22	83.000
5217	HL-17	34-56-58	90-02-43	84.000
5218	HL-18	34-57-45	90-01-40	80.000
5219	HL-19	34-58-15	90-01-20	85.000
5220	HL-20	34-57-45	90-01-00	82.000
5221	HL-21	34-58-47	90-00-19	96.000
5222	HL-22	34-58-20	89-59-55	91.000
5223	HL-23	34-59-02	89-59-13	100.000
5224	HL-24	34-58-39	89-59-13	90.000

WEDNESDAY JUNE 28, 1989 (179)

SESSION 1	SESSION 2	SESSION 3
HUDGINS (3095)	HUDGINS (3095)	HUDGINS (3095)
P-13-2-89(4098)	P-13-2-89(4098)	P-13-2-89(4098)
HOLMES (3094)	HOLMES (3094)	ROVER 2 BEGIN
LYNCHBURG(1096)	P-13-1-89(4097)	ROVER 1 BEGIN
START: 15:40	START: 17:05	START: 18:05
STOP: 16:50	STOP: 18:00	STOP: 20:45
SV's:03,06,08,09, 11,12,13,14	SV's:03,06,08,09 11,12,13,14	SV's:03,06,08,09, 11,12,13,14

Figure E-8. Observation schedule

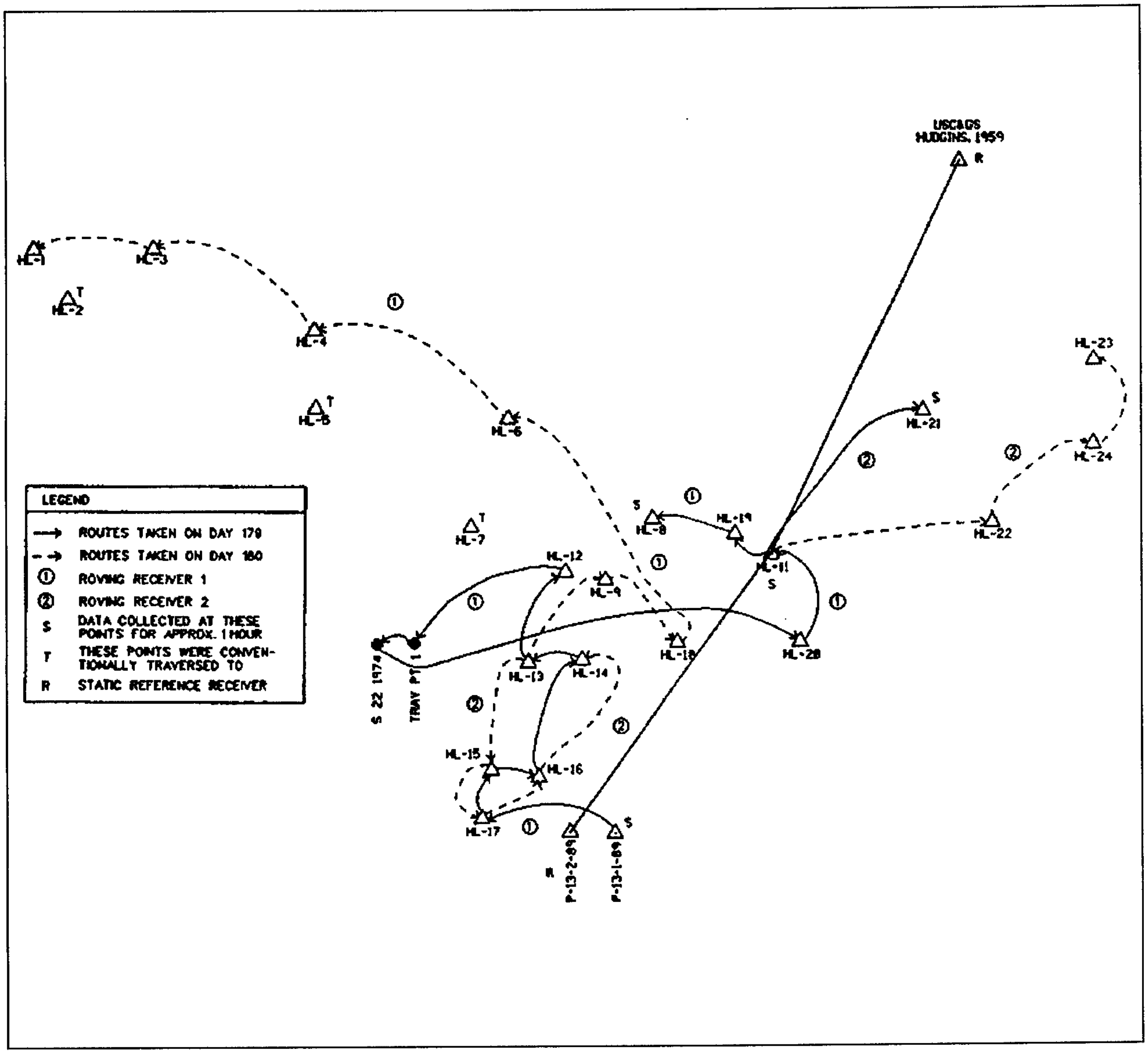

Figure E-9. Observation routes and initialization of rover 1

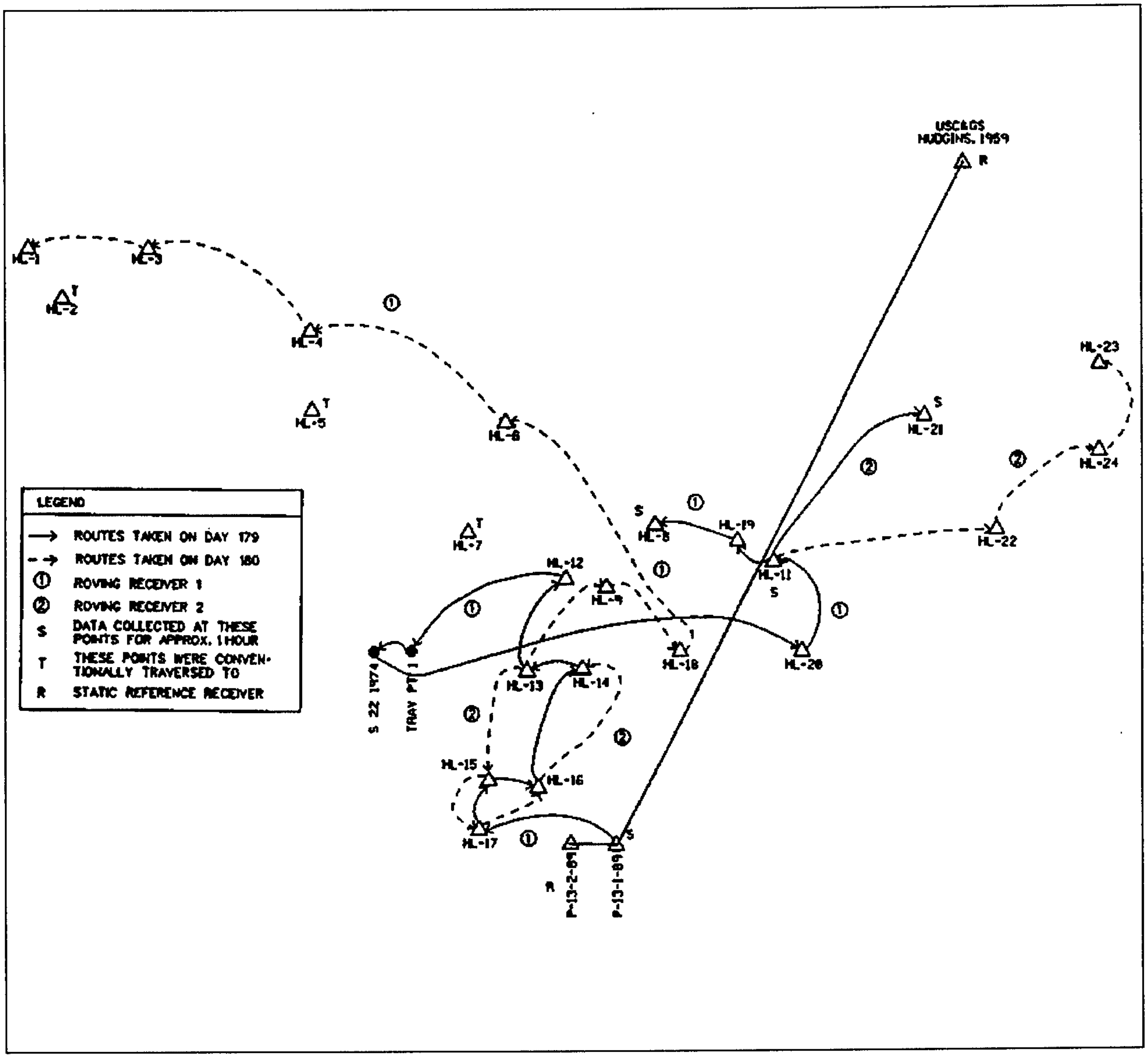

Figure E-10. Observation routes and initialization of rover 2

U.S. ARMY CORPS OF ENGINEERS
STOP & GO KINEMATIC GPS FIELD FORM

****
PROJECT NAME ______________________ LOCALITY ________________
OBSERVER ______________________ AGENCY/FIRM ________________
RECEIVER ______________________ S/N ________________
ANTENNA ______________________ S/N ________________
DATA RECORDING UNIT ______________________ S/N ________________
ANTENNA MOUNTING DEVICE ______________________ LAST CALIBRATED: ________
DATE (MM DD YY) ______________________ DAY OF YEAR ________________
****

STATIC REFERENCE RECEIVERS

	RECEIVER 1		RECEIVER 2		RECEIVER 3	
STATION NAME						
STATION NUMBER						
UTC TIME OF OBSERVATION	START	STOP	START	STOP	START	STOP

****

STOP & GO ROVING RECEIVER

STATION NUMBER	STATION NAME	ANTENNA HEIGHT	DATA SET #	COMMENTS

PAGE 1 SHEET ____ OF ____

Figure E-11. Stop-and-go kinematic field form (Continued)

U.S. ARMY CORPS OF ENGINEERS
STOP & GO KINEMATIC GPS FIELD FORM

****
STOP & GO ROVING RECEIVER CON'T

STATION NUMBER	STATION NAME	ANTENNA HEIGHT	DATA SET #	COMMENTS

****
ADDITIONAL COMMENTS

PAGE 2

Figure E-11. (Concluded)

U.S. ARMY CORPS OF ENGINEERS
STOP & GO KINEMATIC GPS FIELD FORM

PROJECT NAME Horn Lake Creek GPS-7K LOCALITY Horn Lake, Ms
OBSERVER C. Waite & C.D. Wilbanks AGENCY/FIRM CoE, Memphis District
RECEIVER Trimble 4000 SL S/N 2820A00242
ANTENNA Trimble Micro SL S/N 2923A00242
DATA RECORDING UNIT Receiver S/N 2820A00242
ANTENNA MOUNTING DEVICE Range Pole & Bipod LAST CALIBRATED: 06/27/89
DATE (MM DD YY) 06/28/89 DAY OF YEAR 179

STATIC REFERENCE RECEIVERS

	RECEIVER 1		RECEIVER 2		RECEIVER 3	
STATION NAME	HUDGINS		P-13-2-89			
STATION NUMBER	3095		4098			
UTC TIME OF OBSERVATION	START 20:39	STOP 01:45	START 22:03	STOP 01:46	START	STOP

STOP & GO ROVING RECEIVER

STATION NUMBER	STATION NAME	ANTENNA HEIGHT	DATA SET #	COMMENTS
4097	P-13-1-89	1.963	1	Static Initialization 22:04 - 23:00 UTC Lost Lock Traveling To Next Pt.
4097	P-13-1-89	"	2	Returned To Reinitialize
5217	HL-17	"	3	Antenna Disturbed
5217	HL-17	"	4	Reoccupied
5215	HL-15	"	5	
7211	Return Pt A	"	6	PK Nail at ℄ of NW End of Meadowbrook Rd Bridge over Cow Pen Creek
5216	HL-16	"	7	
5214	HL-14	"	8	
5213	HL-13	"	9	
5212	HL-12	"	10	
7212	Trav Pt-1	"	11	PK Nail at N/Edge Goodman Rd 0.45 M E of Horn Lake Rd.
2099	522 1974	"	12	Bench Mark on Culvert Headwall
5220	HL-20	"	13	

PAGE 1 SHEET 1 OF 1

Figure E-12. Example stop-and-go kinematic field form (Continued)

U.S. ARMY CORPS OF ENGINEERS
STOP & GO KINEMATIC GPS FIELD FORM

****

STOP & GO ROVING RECEIVER CON'T

STATION NUMBER	STATION NAME	ANTENNA HEIGHT	DATA SET #	COMMENTS
5211	HL-11	1.963	14	
5219	HL-19	"	15	
5208	HL-8	"	16	LOST LOCK TRAVELING TO THIS POINT OCCUPIED STATICALLY FROM 00:42 TO 01:45 UTC

****

ADDITIONAL COMMENTS

7212-TRAV PT 1 AND 2099-S22 1974 WILL BE USED AS BEGINNING AND ENDING HORIZONTAL CONTROL FOR TRAVERSE TO HL-7. S22 1974 WILL BE USED AS VERTICAL CONTROL FOR DIFFERENTIAL LEVELS TO HL-7.

PAGE 2

Figure E-12. (Concluded)

```
TRIMVEC GPS RELATIVE POSITIONING SOLUTION SUMMARY:  VERSION 89.062

SOLUTION OUTPUT FILE: D:\179\OUT\95971792.fix

STATION 1:   Station ID: 3095  Session #: 179-1     Jun 28, 1989 19:22
Data-logging start time = 20:39     Data-logging stop  time = 01:45

STATION 2:   Station ID: 4097  Session #: 179-2     Jun 28, 1989 22:04
Data-logging start time = 22:04     Data-logging stop  time = 23:00

STATION COORDINATES:

Sta         Ant (m)      Latitude              Longitude             Hgt (m)
 1           1.409    34:59'52.56136" N    90:00'07.30092" W        106.019
 2 [TRP]     1.963    34:56'53.54740" N    90:02'03.76506" W         91.051
 2 [FLT]     1.963    34:56'53.54594" N    90:02'03.76283" W         91.073
 2 [FIX]     1.963    34:56'53.54605" N    90:02'03.76258" W         91.089

Origin of station 1 coordinates : User input

SOLUTION SUMMARY:

Solution        dx (m)         dy (m)         dz (m)       dh (m)      RDOP
TRIPLE       -2955.290      -3148.922      -4529.085      -14.969     4.329
FLOAT        -2955.234      -3148.966      -4529.109      -14.946     0.354
*FIXED       -2955.228      -3148.977      -4529.097      -14.930     0.048
FLT-FIX         -0.006          0.011         -0.012       -0.015

Solution  Slope (m)     sig    Epochs/Rejected  Epoch interval  Epoch increment
TRIPLE    6257.9599  [0.064]     102/  6           150 (secs)      5 (epochs)
FLOAT     6257.9727  [0.032]     546/ 27            30 (secs)      1 (epochs)
FIXED     6257.9668  [0.014]     545/ 28            30 (secs)      1 (epochs)

Fixed solution quality factor:   10.1
Fixed solution rms:             0.039 (cycles)
Maximum float - fixed delta:      1.2 (cm)

Integers found, RMS is OK, FIXED solution recommended.
```

Figure E-13. Static solution summary 3095 -> 4097

```
TRIMVEC GPS RELATIVE POSITIONING SOLUTION SUMMARY:  VERSION 89.062

SOLUTION OUTPUT FILE: D:\179\OUT\98971792.fix

STATION 1:    Station ID: 4098  Session #: 179-1     Jun 28, 1989 20:38
Data-logging start time = 20:42     Data-logging stop  time = 01:45

STATION 2:    Station ID: 4097  Session #: 179-2     Jun 28, 1989 22:04
Data-logging start time = 22:04     Data-logging stop  time = 23:00

STATION COORDINATES:

Sta         Ant (m)      Latitude            Longitude              Hgt (m)
 1            1.590   34:56'53.35126" N   90:02'18.20974" W          83.300
 2 [TRP]      1.963   34:56'53.54487" N   90:02'03.76471" W          91.136
 2 [FLT]      1.963   34:56'53.54503" N   90:02'03.76453" W          91.114
 2 [FIX]      1.963   34:56'53.54458" N   90:02'03.76338" W          91.120

Origin of station 1 coordinates : User input

SOLUTION SUMMARY:

Solution        dx (m)          dy (m)          dz (m)       dh (m)      RDOP
TRIPLE          366.528         -3.238           9.379        7.836      4.303
FLOAT           366.523         -3.217           9.371        7.814      0.354
*FIXED          366.562         -3.230           9.363        7.820      0.047
FLT-FIX          -0.029          0.013           0.008       -0.006

Solution  Slope (m)    sig     Epochs/Rejected  Epoch interval  Epoch increment
TRIPLE    366.6626  [0.106]       107/  1         150 (secs)        5 (epochs)
FLOAT     366.6667  [0.006]       570/  3          30 (secs)        1 (epochs)
FIXED     366.6960  [0.002]       569/  4          30 (secs)        1 (epochs)

Fixed solution quality factor:    29.7
Fixed solution rms:              0.024 (cycles)
Maximum float - fixed delta:       2.9 (cm)

Integers found, RMS is large. (see Trimvec Manual).
```

Figure E-14. Static solution summary 4098 -> 4097

quality factors were fairly high, meaning that the integer-cycle ambiguities were resolved in both solutions with a high degree of reliability. Even though the RMS was slightly large in comparison to the length of the baseline from 4098 to 4097, the fixed solution quality factor was high and thus the results of the fixed solution are recommended. Had sufficient data not been collected to resolve the integer cycle ambiguities, additional static data collection would be required. An attempt to process stop-and-go data using values from static solutions in which the integers were not found may give erroneous results for the baselines processed. The dX, dY, and dZ values listed for the fixed solution in Figures E-13 and E-14 were used to post-process the stop-and-go data.

b. After all static data were processed, summaries of the stop-and-go sessions were printed. These summaries document the events of the session and the time of their occurrence in GPS seconds of the week. Figure E-15 shows the summary of events that took place during the stop-and-go session on day 179 between the reference receiver at station 3095 and roving receiver initializing on station 4097. The stop-and-go session summary conveys the following details of the survey.

(1) The data file names for the reference and remote (roving) receivers.

(2) The kinematic (stop-and-go) data set number. This number was automatically incremented by one each time a point was occupied.

(3) The station ID of the point being occupied.

(4) The time in seconds that the data set began.

(5) The height of the roving receiver's antenna above the point being occupied.

(6) The time in seconds that the data set ended.

(7) The amount of time in minutes and seconds that data were recorded at the point being occupied.

(8) The last epoch of data recorded before missing satellite PRN 14. The satellite was missing because a cycle slip occurred or a loss of data occurred during download from the receiver to the computer.

(9) The last epoch of data recorded before a cycle slip occurred on satellite PRN 6.

(10) The number of satellites the receiver was locked onto after missing PRN 14 and a cycle slip on PRN 6.

(11) At this point, lock was not maintained on at least four satellites. The survey was reinitialized by returning to the last point occupied; also a new route was chosen to the next point.

(12) The travel time in minutes and seconds that it took to move to the next point, or in this case, to go back to the last occupied point.

(13) The typical observation time at each stop-and-go point.

(14) At this point, lock could not be maintained on at least four satellites. The low elevation of the remaining visible satellites indicated that reinitialization would have been futile.

(15) Since there was slightly over an hour of the four-satellite window remaining on day 179, the survey continued to station 5208 where static observations were recorded for 63 minutes.

(16) Stations within a linked data set were stations consecutively occupied while lock was maintained on at least four satellites. At the point when lock was no longer maintained on at least four satellites, a new linked data set was started.

(17) The station occupation data indicate how many times each point was occupied and to which data set each occupation corresponds.

Figure E-16 shows the summary of events that took place during the stop-and-go session on day 179 between the reference receiver at station 4098 and roving receiver initializing on station 4097. Figures E-15 and E-16 are similar, but they are not exactly the same. A comparison of the two summaries reveals that other than the reference receivers being at different locations, the only other difference is in some of the times when cycle slips or missing satellite data occurred. Since the data from the roving receiver were common to both summaries, the differences in times of missing satellite data were due to obstructions at the reference receiver's location. The roving receiver operator can observe only cycle slips occurring at his receiver. Each receiver in the stop-and-go mode is able to warn the operator with a series of beeps when it no

```
Trimble Automated Kinematic Processor,  Version 83.120
Kinematic Summary of Session: 179

Reference Receiver Data File: 30951791  a
Remote Receiver Data File:    40971792
Reference PRN #:              11
                          b           c                    d                 e
KINEMATIC DATA SET:   1   ID: 4097    Time:    338835   Ant height: 2.0000
   New Scenario Add  SV    PRN: 12    Time:    339210
    SV Count:           6             Time:    339210
    Last Before Missing    PRN: 12    Time:    339360
    SV Count:           5             Time:    339360
           Recovered SV    PRN: 12    Time:    339405   *STATIC INITIALIZATION
    SV Count:           6             Time:    339405    (OR KNOWN BASELINE
   New Scenario Add  SV    PRN: 14    Time:    340260     AFTER PROCESSING)
    SV Count:           7             Time:    340260
END OF KINEMATIC DATA     ID: 4097    Time:    341985 f  Ant height: 2.0000
OBSERVATION TIME: 55:15 g

    Last Before Missing    PRN: 14    Time:    342225 h
       Last Before Slip    PRN:  6    Time:    342225   i
    SV Count:           5 j           Time:    342225
       Last Before Slip    PRN:  8    Time:    342240
       Last Before Slip    PRN:  9    Time:    342240
       Last Before Slip    PRN: 11    Time:    342240
       Last Before Slip    PRN: 12    Time:    342240
       Last Before Slip    PRN: 13    Time:    342240
    SV Count:           0             Time:    342240
       After Cycle Slip    PRN:  6    Time:    342270   *LOST LOCK ON SATELLITES
       After Cycle Slip    PRN:  8    Time:    342270    WHILE MOVING, RETURNED
       After Cycle Slip    PRN:  9    Time:    342270    TO LAST OCCUPIED POINT.
       After Cycle Slip    PRN: 11    Time:    342270    (SEE DATA SET 2 BELOW)
       After Cycle Slip    PRN: 12    Time:    342270
           Recovered SV    PRN: 14    Time:    342270
    SV Count:           6             Time:    342270
       After Cycle Slip    PRN: 13    Time:    342315
    SV Count:           7             Time:    342315
       Last Before Slip    PRN:  6    Time:    342330
       Last Before Slip    PRN: 14    Time:    342330
    SV Count:           5             Time:    342330
       After Cycle Slip    PRN: 14    Time:    342375
    SV Count:           6             Time:    342375
       After Cycle Slip    PRN:  6    Time:    342420
    Last Before Missing    PRN:  8    Time:    342420
    Last Before Missing    PRN: 14    Time:    342420
    SV Count:           5             Time:    342420
           Recovered SV    PRN:  8    Time:    342465
    SV Count:           6             Time:    342465
           Recovered SV    PRN: 14    Time:    342480
    SV Count:           7             Time:    342480
 MOVE TIME:  9:44 l

 KINEMATIC DATA SET:  2   ID: 4097    Time:    342585   Ant height: 2.0000
 END OF KINEMATIC DATA    ID: 4097    Time:    342645   Ant height: 2.0000
 OBSERVATION TIME:  1:15  *RETURNED TO REINITIALIZE WITH KNOWN BASELINE
                      m
```

Figure E-15. Kinematic session summary 3095 -> 4097 (Sheet 1 of 6)

```
      Last Before Slip   PRN:  6    Time:    342810
   SV Count:                6       Time:    342810
      After Cycle Slip   PRN:  6    Time:    342840
   SV Count:                7       Time:    342840
MOVE TIME:  6:59

KINEMATIC DATA SET:  3   ID: 5217   Time:    343080    Ant height: 2.0000
END OF KINEMATIC DATA    ID: 5217   Time:    343260    Ant height: 2.0000
OBSERVATION TIME:  3:15  *SETUP WAS DISTURBED DURING OCCUPATION,
                          SEE DATA SET 4 FOR REOCCUPATION

MOVE TIME:  0:59

KINEMATIC DATA SET:  4   ID: 5217   Time:    343335    Ant height: 2.0000
END OF KINEMATIC DATA    ID: 5217   Time:    343395    Ant height: 2.0000
OBSERVATION TIME:  1:15

    Last Before Missing   PRN:  8   Time:    343545
    SV Count:               6       Time:    343545
MOVE TIME:  4: 0

KINEMATIC DATA SET:  5   ID: 5215   Time:    343650    Ant height: 2.0000
KINEMATIC DATA SET:  5   ID: 5215   Time:    343680    Ant height: 2.0000
              Recovered SV   PRN:  8   Time:    343710
    SV Count:               7       Time:    343710
END OF KINEMATIC DATA    ID: 5215   Time:    343710    Ant height: 2.0000
OBSERVATION TIME:  1:15

    Last Before Missing   PRN:  8   Time:    343845
    SV Count:               6       Time:    343845
              Recovered SV   PRN:  8   Time:    343935
    Last Before Missing   PRN:  6   Time:    343935
              Recovered SV   PRN:  6   Time:    343965
    SV Count:               7       Time:    343965
    Last Before Missing   PRN:  8   Time:    343980
    SV Count:               6       Time:    343980
    Last Before Missing   PRN:  6   Time:    344010
    SV Count:               5       Time:    344010
              Recovered SV   PRN:  6   Time:    344130
    SV Count:               6       Time:    344130
MOVE TIME:  7:14

KINEMATIC DATA SET:  6   ID: 7211   Time:    344160    Ant height: 2.0000
KINEMATIC DATA SET:  6   ID: 7211   Time:    344220    Ant height: 2.0000
END OF KINEMATIC DATA    ID: 7211   Time:    344220    Ant height: 2.0000
OBSERVATION TIME:  1:15  *THIS POINT WAS ESTABLISHED TO RETURN TO IN CASE
                          LOCK WAS LOST ON THE WAY TO POINT 5216

    Last Before Missing   PRN:  6   Time:    344250
    SV Count:               5       Time:    344250
  New Scenario Lost SV    PRN:  6   Time:    344415
MOVE TIME:  4:14

KINEMATIC DATA SET:  7   ID: 5216   Time:    344490    Ant height: 2.0000
END OF KINEMATIC DATA    ID: 5216   Time:    344550    Ant height: 2.0000
OBSERVATION TIME:  1:15
```

Figure E-15. (Sheet 2 of 6)

```
      Last Before Slip   PRN: 12   Time:   344700
   SV Count:            4          Time:   344700
          Recovered SV   PRN:  8   Time:   344730
   SV Count:            5          Time:   344730
      After Cycle Slip   PRN: 12   Time:   344745
   SV Count:            6          Time:   344745
   Last Before Missing   PRN:  8   Time:   344760
   SV Count:            5          Time:   344760
MOVE TIME:  6:29

KINEMATIC DATA SET:  8   ID: 5214  Time:   344955   Ant height: 2.0000
END OF KINEMATIC DATA    ID: 5214  Time:   345015   Ant height: 2.0000
OBSERVATION TIME:  1:15

          Recovered SV   PRN:  8   Time:   345165
      Last Before Slip   PRN:  8   Time:   345165
      After Cycle Slip   PRN:  8   Time:   345210
   SV Count:            6          Time:   345210
      Last Before Slip   PRN:  8   Time:   345270
   SV Count:            5          Time:   345270
  New Scenario Lost SV   PRN:  8   Time:   345330
MOVE TIME:  5:30

KINEMATIC DATA SET:  9   ID: 5213  Time:   345360   Ant height: 2.0000
END OF KINEMATIC DATA    ID: 5213  Time:   345420   Ant height: 2.0000
OBSERVATION TIME:  1:14

MOVE TIME:  6: 0

KINEMATIC DATA SET: 10   ID: 5212  Time:   345795   Ant height: 2.0000
END OF KINEMATIC DATA    ID: 5212  Time:   345855   Ant height: 2.0000
OBSERVATION TIME:  1:15

  New Scenario Add  SV   PRN:  3   Time:   345900
   SV Count:            6          Time:   345900
   Last Before Missing   PRN:  3   Time:   345960
   SV Count:            5          Time:   345960
          Recovered SV   PRN:  3   Time:   346050
   SV Count:            6          Time:   346050
MOVE TIME:  6:44

KINEMATIC DATA SET: 11   ID: 7212  Time:   346275   Ant height: 2.0000
END OF KINEMATIC DATA    ID: 7212  Time:   346335   Ant height: 2.0000
OBSERVATION TIME:  1:15

      Last Before Slip   PRN:  3   Time:   346485
   SV Count:            5          Time:   346485
      After Cycle Slip   PRN:  3   Time:   346515
   SV Count:            6          Time:   346515
MOVE TIME:  3:14

KINEMATIC DATA SET: 12   ID: 2099  Time:   346545   Ant height: 2.0000
END OF KINEMATIC DATA    ID: 2099  Time:   346620   Ant height: 2.0000
OBSERVATION TIME:  1:30
```

Figure E-15. (Sheet 3 of 6)

```
      Last Before Slip   PRN:  9    Time:    346815
   SV Count:           5            Time:    346815
      After Cycle Slip   PRN:  9    Time:    346845
   SV Count:           6            Time:    346845
   Last Before Missing   PRN:  9    Time:    346890
   SV Count:           5            Time:    346890
          Recovered SV   PRN:  9    Time:    346935
      Last Before Slip   PRN:  9    Time:    346935
      After Cycle Slip   PRN:  9    Time:    347010
   SV Count:           6            Time:    347010
MOVE TIME:  8:15

KINEMATIC DATA SET: 13   ID: 5220   Time:    347130    Ant height: 2.0000
END OF KINEMATIC DATA    ID: 5220   Time:    347190    Ant height: 2.0000
OBSERVATION TIME:   1:15

MOVE TIME:  4:29

KINEMATIC DATA SET: 14   ID: 5211   Time:    347475    Ant height: 2.0000
END OF KINEMATIC DATA    ID: 5211   Time:    347535    Ant height: 2.0000
OBSERVATION TIME:   1:15

      Last Before Slip   PRN:  9    Time:    347730
   SV Count:           5            Time:    347730
      After Cycle Slip   PRN:  9    Time:    347760
   SV Count:           6            Time:    347760
MOVE TIME:  3:45

KINEMATIC DATA SET: 15   ID: 5219   Time:    347775    Ant height: 2.0000
END OF KINEMATIC DATA    ID: 5219   Time:    347835    Ant height: 2.0000
OBSERVATION TIME:   1:15

   Last Before Missing   PRN:  9    Time:    347895
      Last Before Slip   PRN:  3    Time:    347895
   SV Count:           4            Time:    347895
      After Cycle Slip   PRN:  3    Time:    347940
      Last Before Slip   PRN:  3    Time:    347940
      Last Before Slip   PRN: 11    Time:    347940
   SV Count:           3            Time:    347940 71 *AT THIS POINT LOCK WAS
      After Cycle Slip   PRN: 11    Time:    347970     NOT MAINTAINED ON AT
   SV Count:           4            Time:    347970     LEAST 4 SATELLIES
      Last Before Slip   PRN: 13    Time:    347986
   SV Count:           3            Time:    347986
   Last Before Missing   PRN: 12    Time:    348000
   SV Count:           2            Time:    348000
      After Cycle Slip   PRN:  3    Time:    348015
      After Cycle Slip   PRN: 13    Time:    348015
      Last Before Slip   PRN:  3    Time:    348015
      Last Before Slip   PRN: 11    Time:    348015
      Last Before Slip   PRN: 13    Time:    348015
      Last Before Slip   PRN: 14    Time:    348015
   SV Count:           0            Time:    348015
```

Figure E-15. (Sheet 4 of 6)

```
        After Cycle Slip    PRN: 11    Time:    348045
            Recovered SV    PRN: 12    Time:    348045
        After Cycle Slip    PRN: 14    Time:    348045
        Last Before Slip    PRN: 12    Time:    348045
     SV Count:             2           Time:    348045
        After Cycle Slip    PRN:  3    Time:    348075
        After Cycle Slip    PRN: 12    Time:    348075
        After Cycle Slip    PRN: 13    Time:    348075
     SV Count:             5           Time:    348075
            Recovered SV    PRN:  9    Time:    348090
     SV Count:             6           Time:    348090
MOVE TIME:   5: 0

KINEMATIC DATA SET: 16    ID: 5208 O Time:    348150    Ant height: 2.0000
KINEMATIC DATA SET: 16    ID: 5208   Time:    348195    Ant height: 2.0000
    Last Before Missing    PRN:  9   Time:    348420
    SV Count:             5          Time:    348420   *DUE TO THE ABOVE LOSS OF
   New Scenario Lost SV    PRN:  9   Time:    348435    LOCK, THIS POINT WAS
    Last Before Missing    PRN: 12   Time:    351180    OCCUPIED FOR 63 MINUTES
    SV Count:             4          Time:    351180    AND THE DATA PROCESSED
   New Scenario Lost SV    PRN: 12   Time:    351195    AS A STATIC BASELINE.
END OF KINEMATIC DATA     ID: 5208   TIME:    351930
OBSERVATION TIME: 63:00

 Linked Data Set # 1:    - 4097
P Linked Data Set # 2:    - 4097 - 5217 - 5217 - 5215 - 7211 - 5216 - 5214
                         - 5213 - 5212 - 7212 - 2099 - 5220 - 5211 - 5219
 Linked Data Set # 3:    - 5208
```

Figure E-15. (Sheet 5 of 6)

```
                    STATION OCCUPATION INFORMATION
                    ------------------------------

MARK ID: 4097   Occupations:   2
Data Set ID:    1
Data Set ID:    2

MARK ID: 5217   Occupations:   2
Data Set ID:    3
Data Set ID:    4

MARK ID: 5219   Occupations:   1
Data Set ID:   15

MARK ID: 5215   Occupations:   1
Data Set ID:    5

MARK ID: 5216   Occupations:   1
Data Set ID:    7

MARK ID: 7211   Occupations:   1
Data Set ID:    6

MARK ID: 5214   Occupations:   1
Data Set ID:    8

MARK ID: 5213   Occupations:   1
Data Set ID:    9

MARK ID: 5212   Occupations:   1
Data Set ID:   10

MARK ID: 7212   Occupations:   1
Data Set ID:   11

MARK ID: 2099   Occupations:   1
Data Set ID:   12

MARK ID: 5220   Occupations:   1
Data Set ID:   13

MARK ID: 5211   Occupations:   1
Data Set ID:   14

MARK ID: 5208   Occupations:   1
Data Set ID:   16
```

Figure E-15. (Sheet 6 of 6)

```
Trimble Automated Kinematic Processor,  Version 89.120
Kinematic Summary of Session: 179

Reference Receiver Data File: 40981791
Remote Receiver Data File:    40971792
Reference PRN #:              11

KINEMATIC DATA SET:  1    ID: 4097   Time:    338835    Ant height: 2.0000
   New Scenario Add  SV    PRN: 12   Time:    339210
    SV Count:             6          Time:    339210
    Last Before Missing    PRN: 12   Time:    339360
    SV Count:             5          Time:    339360    *STATIC INITIALIZATION
           Recovered SV    PRN: 12   Time:    339405     (OR KNOWN BASELINE
    SV Count:             6          Time:    339405      AFTER PROCESSING)
   New Scenario Add  SV    PRN: 14   Time:    340320
    Last Before Missing    PRN: 14   Time:    340320
           Recovered SV    PRN: 14   Time:    340425
    SV Count:             7          Time:    340425
END OF KINEMATIC DATA      ID: 4097  Time:    341985    Ant height: 2.0000
OBSERVATION TIME: 55:15

    Last Before Missing    PRN: 14   Time:    342225
       Last Before Slip    PRN:  6   Time:    342225
    SV Count:             5          Time:    342225
       Last Before Slip    PRN:  8   Time:    342240
       Last Before Slip    PRN:  9   Time:    342240
       Last Before Slip    PRN: 11   Time:    342240
       Last Before Slip    PRN: 12   Time:    342240
       Last Before Slip    PRN: 13   Time:    342240
    SV Count:             0          Time:    342240    *LOST LOCK ON SATELLITES
       After Cycle Slip    PRN:  6   Time:    342270     WHILE MOVING, RETURNED
       After Cycle Slip    PRN:  8   Time:    342270     TO LAST OCCUPIED POINT.
       After Cycle Slip    PRN:  9   Time:    342270     (SEE DATA SET 2 BELOW)
       After Cycle Slip    PRN: 11   Time:    342270
       After Cycle Slip    PRN: 12   Time:    342270
           Recovered SV    PRN: 14   Time:    342270
    SV Count:             6          Time:    342270
       After Cycle Slip    PRN: 13   Time:    342315
    SV Count:             7          Time:    342315
       Last Before Slip    PRN:  6   Time:    342330
       Last Before Slip    PRN: 14   Time:    342330
    SV Count:             5          Time:    342330
       After Cycle Slip    PRN: 14   Time:    342375
    SV Count:             6          Time:    342375
       After Cycle Slip    PRN:  6   Time:    342420
    Last Before Missing    PRN:  8   Time:    342420
    Last Before Missing    PRN: 14   Time:    342420
    SV Count:             5          Time:    342420
           Recovered SV    PRN:  8   Time:    342465
    SV Count:             6          Time:    342465
           Recovered SV    PRN: 14   Time:    342480
    SV Count:             7          Time:    342480
 MOVE TIME:  9:44
```

Figure E-16. Kinematic session summary 4098 -> 4097 (Sheet 1 of 6)

```
KINEMATIC DATA SET:  2    ID: 4097   Time:    342585    Ant height: 2.0000
END OF KINEMATIC DATA     ID: 4097   Time:    342645    Ant height: 2.0000
OBSERVATION TIME:  1:15   *RETURNED TO REINITIALIZE WITH KOWN BASELINE

       Last Before Slip    PRN:  6   Time:    342810
    SV Count:            6           Time:    342810
       After Cycle Slip    PRN:  6   Time:    342840
    SV Count:            7           Time:    342840
MOVE TIME:  6:59

KINEMATIC DATA SET:  3    ID: 5217   Time:    343080    Ant height: 2.0000
END OF KINEMATIC DATA     ID: 5217   Time:    343260    Ant height: 2.0000
OBSERVATION TIME:  3:15   *SETUP DISTURBED DURING OCCUPATION,
                           SEE DATA SET 4 FOR REOCCUPATION.
MOVE TIME:  0:59

KINEMATIC DATA SET:  4    ID: 5217   Time:    343335    Ant height: 2.0000
END OF KINEMATIC DATA     ID: 5217   Time:    343395    Ant height: 2.0000
OBSERVATION TIME:  1:15

MOVE TIME:  4: 0

KINEMATIC DATA SET:  5    ID: 5215   Time:    343650    Ant height: 2.0000
KINEMATIC DATA SET:  5    ID: 5215   Time:    343680    Ant height: 2.0000
END OF KINEMATIC DATA     ID: 5215   Time:    343710    Ant height: 2.0000
OBSERVATION TIME:  1:15

    Last Before Missing    PRN:  8   Time:    343845
    SV Count:            6           Time:    343845
           Recovered SV    PRN:  8   Time:    343935
    Last Before Missing    PRN:  6   Time:    343935
           Recovered SV    PRN:  6   Time:    343965
    SV Count:            7           Time:    343965
    Last Before Missing    PRN:  6   Time:    344010
    SV Count:            6           Time:    344010
    Last Before Missing    PRN:  8   Time:    344055
    SV Count:            5           Time:    344055
           Recovered SV    PRN:  6   Time:    344130
    Last Before Missing    PRN:  6   Time:    344130
   New Scenario Lost SV    PRN:  6   Time:    344145
           Recovered SV    PRN:  8   Time:    344145
    SV Count:            6           Time:    344145
MOVE TIME:  7:14

KINEMATIC DATA SET:  6    ID: 7211   Time:    344160    Ant height: 2.0000
KINEMATIC DATA SET:  6    ID: 7211   Time:    344220    Ant height: 2.0000
END OF KINEMATIC DATA     ID: 7211   Time:    344220    Ant height: 2.0000
OBSERVATION TIME:  1:15    *THIS POINT WAS ESTABLISHED TO RETURN TO IN CASE
                            LOCK WAS LOST ON THE WAY TO POINT 5216.
       Last Before Slip    PRN:  8   Time:    344295
    SV Count:            5           Time:    344295
       After Cycle Slip    PRN:  8   Time:    344340
    SV Count:            6           Time:    344340
    Last Before Missing    PRN:  8   Time:    344370
    SV Count:            5           Time:    344370
           Recovered SV    PRN:  8   Time:    344430
    SV Count:            6           Time:    344430
MOVE TIME:  4:14
```

Figure E-16. (Sheet 2 of 6)

```
KINEMATIC DATA SET:  7    ID: 5216    Time:    344490     Ant height: 2.0000
END OF KINEMATIC DATA     ID: 5216    Time:    344550     Ant height: 2.0000
OBSERVATION TIME:  1:15

    Last Before Missing   PRN:  8    Time:    344655
    SV Count:            5           Time:    344655
       Last Before Slip   PRN: 12    Time:    344700
    SV Count:            4           Time:    344700
           Recovered SV   PRN:  8    Time:    344730
    SV Count:            5           Time:    344730
       After Cycle Slip   PRN: 12    Time:    344745
    SV Count:            6           Time:    344745
    Last Before Missing   PRN:  8    Time:    344775
    SV Count:            5           Time:    344775
           Recovered SV   PRN:  8    Time:    344865
    SV Count:            6           Time:    344865
MOVE TIME:  6:29

KINEMATIC DATA SET:  8    ID: 5214    Time:    344955     Ant height: 2.0000
END OF KINEMATIC DATA     ID: 5214    Time:    345015     Ant height: 2.0000
OBSERVATION TIME:  1:15

    Last Before Missing   PRN:  8    Time:    345090
    SV Count:            5           Time:    345090
           Recovered SV   PRN:  8    Time:    345165
       Last Before Slip   PRN:  8    Time:    345165
       After Cycle Slip   PRN:  8    Time:    345210
    SV Count:            6           Time:    345210
       Last Before Slip   PRN:  8    Time:    345270
    SV Count:            5           Time:    345270
       After Cycle Slip   PRN:  8    Time:    345345
    SV Count:            6           Time:    345345
MOVE TIME:  5:30

KINEMATIC DATA SET:  9    ID: 5213    Time:    345360     Ant height: 2.0000
END OF KINEMATIC DATA     ID: 5213    Time:    345420     Ant height: 2.0000
OBSERVATION TIME:  1:14

    Last Before Missing   PRN:  8    Time:    345480
    SV Count:            5           Time:    345480
   New Scenario Lost SV   PRN:  8    Time:    345495
MOVE TIME:  6: 0

KINEMATIC DATA SET: 10    ID: 5212    Time:    345795     Ant height: 2.0000
END OF KINEMATIC DATA     ID: 5212    Time:    345855     Ant height: 2.0000
OBSERVATION TIME:  1:15

   New Scenario Add  SV   PRN:  3    Time:    345900
    SV Count:            6           Time:    345900
MOVE TIME:  6:44

KINEMATIC DATA SET: 11    ID: 7212    Time:    346275     Ant height: 2.0000
END OF KINEMATIC DATA     ID: 7212    Time:    346335     Ant height: 2.0000
OBSERVATION TIME:  1:15

       Last Before Slip   PRN:  3    Time:    346485
    SV Count:            5           Time:    346485
       After Cycle Slip   PRN:  3    Time:    346515
    SV Count:            6           Time:    346515
MOVE TIME:  3:14
```

Figure E-16. (Sheet 3 of 6)

```
KINEMATIC DATA SET: 12     ID: 2099    Time:    346545     Ant height: 2.0000
END OF KINEMATIC DATA      ID: 2099    Time:    346620     Ant height: 2.0000
OBSERVATION TIME:  1:30

       Last Before Slip     PRN:  9    Time:    346815
   SV Count:              5            Time:    346815
       After Cycle Slip     PRN:  9    Time:    346845
   SV Count:              6            Time:    346845
   Last Before Missing      PRN:  9    Time:    346890
   SV Count:              5            Time:    346890
           Recovered SV     PRN:  9    Time:    346935
       Last Before Slip     PRN:  9    Time:    346935
       After Cycle Slip     PRN:  9    Time:    347010
   SV Count:              6            Time:    347010
MOVE TIME:  8:15

KINEMATIC DATA SET: 13     ID: 5220    Time:    347130     Ant height: 2.0000
END OF KINEMATIC DATA      ID: 5220    Time:    347190     Ant height: 2.0000
OBSERVATION TIME:  1:15

MOVE TIME:  4:29

KINEMATIC DATA SET: 14     ID: 5211    Time:    347475     Ant height: 2.0000
END OF KINEMATIC DATA      ID: 5211    Time:    347535     Ant height: 2.0000
OBSERVATION TIME:  1:15

       Last Before Slip     PRN:  9    Time:    347730
   SV Count:              5            Time:    347730
       After Cycle Slip     PRN:  9    Time:    347760
   SV Count:              6            Time:    347760
MOVE TIME:  3:45

KINEMATIC DATA SET: 15     ID: 5219    Time:    347775     Ant height: 2.0000
END OF KINEMATIC DATA      ID: 5219    Time:    347835     Ant height: 2.0000
OBSERVATION TIME:  1:15

   Last Before Missing      PRN:  9    Time:    347895
       Last Before Slip     PRN:  3    Time:    347895
   SV Count:              4            Time:    347895
       After Cycle Slip     PRN:  3    Time:    347940
       Last Before Slip     PRN:  3    Time:    347940
       Last Before Slip     PRN: 11    Time:    347940
   SV Count:              3            Time:    347940
       After Cycle Slip     PRN: 11    Time:    347970
   SV Count:              4            Time:    347970
       Last Before Slip     PRN: 13    Time:    347986
   SV Count:              3            Time:    347986     *AT THIS POINT LOCK WAS
   Last Before Missing      PRN: 12    Time:    348000      NOT MAINTAINED ON AT
   SV Count:              2            Time:    348000      LEAST 4 SATELLITES.
       After Cycle Slip     PRN:  3    Time:    348015
       After Cycle Slip     PRN: 13    Time:    348015
       Last Before Slip     PRN:  3    Time:    348015
       Last Before Slip     PRN: 11    Time:    348015
       Last Before Slip     PRN: 13    Time:    348015
       Last Before Slip     PRN: 14    Time:    348015
   SV Count:              0            Time:    348015
       After Cycle Slip     PRN: 11    Time:    348045
           Recovered SV     PRN: 12    Time:    348045
       After Cycle Slip     PRN: 14    Time:    348045
       Last Before Slip     PRN: 12    Time:    348045
```

Figure E-16. (Sheet 4 of 6)

```
       After Cycle Slip   PRN: 11   Time:   348045
           Recovered SV   PRN: 12   Time:   348045
       After Cycle Slip   PRN: 14   Time:   348045
       Last Before Slip   PRN: 12   Time:   348045
    SV Count:            2          Time:   348045
       After Cycle Slip   PRN:  3   Time:   348075
       After Cycle Slip   PRN: 12   Time:   348075
       After Cycle Slip   PRN: 13   Time:   348075
    SV Count:            5          Time:   348075
           Recovered SV   PRN:  9   Time:   348090
    SV Count:            6          Time:   348090
MOVE TIME:  5: 0

 KINEMATIC DATA SET: 16   ID: 5208 O Time:   348150   Ant height: 2.0000
 KINEMATIC DATA SET: 16   ID: 5208  Time:   348195   Ant height: 2.0000
     Last Before Missing   PRN:  9  Time:   348420
     SV Count:            5         Time:   348420   *DUE TO THE ABOVE LOSS OF
    New Scenario Lost SV   PRN:  9  Time:   348435    LOCK, THIS POINT WAS
     Last Before Missing   PRN: 12  Time:   351180    OCCUPIED FOR 63 MINUTES
     SV Count:            4         Time:   351180    AND THE DATA PROCESSED
    New Scenario Lost SV   PRN: 12  Time:   351195    AS A STATIC BASELINE.
 END OF KINEMATIC DATA     ID: 5208  TIME:   351930
 OBSERVATION TIME: 63:00

  Linked Data Set # 1:    - 4097
P Linked Data Set # 2:    - 4097 - 5217 - 5217 - 5215 - 7211 - 5216 - 5214
                          - 5213 - 5212 - 7212 - 2099 - 5220 - 5211 - 5219
  Linked Data Set # 3:    - 5208
```

Figure E-16. (Sheet 5 of 6)

```
                    STATION OCCUPATION INFORMATION
                    ------------------------------

MARK ID: 4097    Occupations:   2
Data Set ID:      1
Data Set ID:      2

MARK ID: 5217    Occupations:   2
Data Set ID:      3
Data Set ID:      4

MARK ID: 5219    Occupations:   1
Data Set ID:     15

MARK ID: 5215    Occupations:   1
Data Set ID:      5

MARK ID: 5216    Occupations:   1
Data Set ID:      7

MARK ID: 7211    Occupations:   1
Data Set ID:      6

MARK ID: 5214    Occupations:   1
Data Set ID:      8

MARK ID: 5213    Occupations:   1
Data Set ID:      9

MARK ID: 5212    Occupations:   1
Data Set ID:     10

MARK ID: 7212    Occupations:   1
Data Set ID:     11

MARK ID: 2099    Occupations:   1
Data Set ID:     12

MARK ID: 5220    Occupations:   1
Data Set ID:     13

MARK ID: 5211    Occupations:   1
Data Set ID:     14

MARK ID: 5208    Occupations:   1
Data Set ID:     16
```

Figure E-16. (Sheet 6 of 6)

longer has lock on at least four satellites. The receiver CANNOT warn the roving receiver operator to reinitialize when a combination of the data from the rover and the data from the reference receiver no longer has lock on at least the same four satellites. If the survey is not reinitialized, the data collected subsequent to the loss of lock cannot be processed. Therefore, to ensure that all data collected can be processed, it is very important to chose a location for the reference receiver that has very little or no obstructions of the sky greater than 15 deg above the horizon.

c. If the stop-and-go data have to be manually post-processed, the rule of thumb is it takes twice as long to process the data as it does to collect it. In other words, if stop-and-go data were collected for 2 hr (including move time), it will take approximately 4 hr to post-process the data. If two reference receivers were utilized, it will take approximately 8 hr because twice as many baselines will have to be processed. Manual processing is very labor intensive because each cycle slip must be fixed before processing can continue. As stated previously, when a cycle slip occurs on a satellite, the integer cycle ambiguity for that satellite becomes unknown. When lock is recovered on the satellite, its integer cycle ambiguity must be once again resolved. The ambiguity is resolved by fixing the cycle slip. Missing satellite data are treated as a cycle slip and also require fixing during post-processing. Processing time varies with the number of cycle slips that occurred during the session; the fewer the cycle slips, the quicker the processing will proceed. The actual stepwise procedures of manual processing are beyond the scope of this manual and may vary depending on the software being used. The receiver manufacturer should be consulted for available post-processing training.

d. Some software has a batch mode for post-processing stop-and-go data. To save hours in post-processing time, this option should always be used when possible. Before stop-and-go data are collected, a thorough understanding of the batch processing requirements is strongly recommended. The field procedures used may be modified to meet the batch processing requirements.

e. All stop-and-go baselines observed on days 179 and 180 were manually post-processed. Figure E-17 shows a solution file for the baseline from the reference receiver at 3095 to the roving receiver at 4097. The file naming convention is different from that used for static solution files. Using the file name shown in Figure E-17 as an example, the convention for an eight-digit file name with a three-character extension is as follows.

40971795.k01

where

4097 = the ID of the station being occupied by the roving receiver

179 = the day of the year observations were recorded

5 = the last digit of the ID of the station being occupied by the reference receiver

k = part of extension denoting the file as kinematic

01 = part of extension that is incremented by one each time a station is reoccupied by the same rover on the same day

The solution output for stop-and-go baselines is very similar to the double-difference fixed solution for static baselines. Refer to the survey examples in Appendix D for an annotated output of a double-difference fixed solution.

f. Figure E-9 indicates stations HL-11, HL-13, HL-14, HL-15, HL-16, and HL-17 were occupied at different times by both rovers. Station HL-11 was occupied statically by rover 2 and kinematically by rover 1. The other five stations were occupied kinematically by both rovers. Table E-1 shows the repeatability of the values within baseline solutions comparing a static fixed solution to a stop-and-go kinematic solution and also two kinematic solutions processed from data obtained on different days. The comparisons are shown for baselines processed from both reference receivers. Analysis indicates the repeatability between the static and kinematic solutions was generally less than 20 ppm and that between the two kinematic solutions was about the same. The repeatability in the Y component was consistently the worst of the three components. The expected setup error of the range pole and bipod is greater than an optical plummet tribrach and tripod. This will affect the repeatability of two kinematic baselines, especially if the baselines are processed from data collected by different rovers. Relatively speaking, these results exceed in all cases Second-Order Class II precision requirements and in all cases but two, Second-Order Class I requirements.

```
                                                07/10/89     13:45:42.30

                        TRIMBLE NAVIGATION, LTD
                         585 NORTH MARY AVENUE
                      SUNNYVALE, CALIFORNIA  94086
                                U.S.A.

                            PROGRAM TRIMVEC
                   GPS RELATIVE POSITIONING SOLUTION
                            VERSION 89.062MB

 File name: 40971795.k01
Coordinate system - WGS-84

Type solution:  Double difference
Value of L12: 1
  L1 solution

Start date/time: 1989/ 6/28     20:39:60.    day of year 179   tow    333600.
Stop  date/time: 1989/ 6/29      1:45: 0.    day of year 180   tow    351900.


Data available:

station:  1
sat:11 |.....................................................................................|
sat: 8 |......................................................                               |
sat: 6 |.................................................                                    |
sat: 9 |.....................................................................                |
sat:13 |               ......................................................................|
sat:12 |                          .......................................................    |
sat:14 |                               ......................................................|
sat: 3 |                                                        .............................|


station:  2
sat:11 |                        ..............................................................|
sat: 8 |                        ...............................                               |
sat: 6 |                        ..........................                                    |
sat: 9 |                        .............................................                 |
sat:13 |                        ..............................................................|
sat:12 |                          .......................................................     |
sat:14 |                               .......................................................|
sat: 3 |                                                        ..............................|

 Broadcast ephemeris file used: D:\179\30951791.eph
```

SATELLITE	IODE	HEALTH	WEEK NO.	TOW(sec)	URA(m)
11	184	0	494	349200.00	2.8
8	52	60	494	342000.00	32.0
6	27	0	494	342030.00	4.0
9	11	0	494	345600.00	2.8
13	69	0	494	349200.00	2.8
12	194	0	494	349200.00	4.0
14	7	0	494	349200.00	5.7
3	245	0	494	349230.00	2.0

Figure E-17. Kinematic solution output 3095 -> 4097 (Sheet 1 of 4)

```
Broadcast satellite clock correction values
   prn          af0                 af1                  af2              toc
    11   -.3036004491D-03   -.5002220860D-11    .0000000000D+00    .3564D+06
     8   -.6075738929D-03   -.5923084245D-10   -.2775557562D-16    .3492D+06
     6   -.2873353660D-03   -.1796252036D-10    .0000000000D+00    .3492D+06
     9   -.3585955128D-03   -.1693933882D-10   -.2775557562D-16    .3528D+06
    13    .4193321802D-03    .2160049917D-11    .0000000000D+00    .3564D+06
    12    .8332398720D-03    .3751865645D-11    .0000000000D+00    .3564D+06
    14    .5646748468D-04    .5911715562D-11    .0000000000D+00    .3564D+06
     3    .1517958008D-03   -.1466560207D-10   -.2775557562D-16    .3564D+06


No message file for station  1

Origin of station 1 coordinates : User input

  STATION (mark)  1 3095

input data file   1 : D:\179\30951791.dat

 antenna height(m)      1.409

met values used:  pressure(mb)          1013.0
                  temperature(deg C)      20.0
                  relative humidity(%)    50.0

  x (m)         -185.143      lat  (dms)  N    34    59   52.56136
  y (m)     -5230645.165      elon (dms)  E   269    59   52.69908
  z (m)      3637739.935      wlon (dms)  W    90     0    7.30092
                              ht  (m)         106.0190

No message file for station  2

  STATION (mark)  2 4097

input data file   1 : D:\179\40971792.dat

 antenna height(m)      1.963

met values used:  pressure(mb)          1013.0
                  temperature(deg C)      20.0
                  relative humidity(%)    50.0

  x (m)        -3140.364      lat  (dms)  N    34    56   53.54605
  y (m)     -5233794.156      elon (dms)  E   269    57   56.23770
  z (m)      3633210.847      wlon (dms)  W    90     2    3.76230
                              ht  (m)          91.1048


Vector   1 originates at station 1 ends at station  2

 Vector Standard Deviations (m) :
                    dx              dy               dz

 Vector     1   .2740151D-02   .6418240D-02   .4906620D-02

 Vector correlation matrix :
               dx(01)      dy(01)      dz(01)

     dx(01)   1.0000000
     dy(01)   -.7430828   1.0000000
     dz(01)    .6281730   -.8394194   1.0000000
```

Figure E-17. (Sheet 2 of 4)

```
STATION 1 TO  STATION  2

slope distance (m)        6257.9635     sigma (m)      .0022

normal section azimuth (dms)  208 10 42.06
vertical angle (dms)             0 -9 53.01

 east(m)   north(m)   up(m)        -2955.109      -5516.259        -17.992

Delta lat(dms)     0    -2   59.01531
Delta lon(dms)     0    -1   56.46138
Delta ht(m)    -14.9142

 correlations for baseline  1:

                   dx          dy          dz        trop      bias 1      bias 2
               bias 3      bias 4      bias 5      bias 6      bias 7
        dx  1.0000000
        dy  -.7430828   1.0000000
        dz   .6281730   -.8394194   1.0000000
      trop   .0000000    .0000000    .0000000   1.0000000
    bias 1   .0000000    .0000000    .0000000    .0000000   1.0000000
    bias 2   .0000000    .0000000    .0000000    .0000000    .0000000   1.0000000
    bias 3   .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
            1.0000000
    bias 4   .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
             .0000000   1.0000000
    bias 5   .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
             .0000000    .0000000   1.0000000
    bias 6   .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
             .0000000    .0000000    .0000000   1.0000000
    bias 7   .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
             .0000000    .0000000    .0000000    .0000000   1.0000000

                            Solution       Sigma
    dx (m)                 -2955.220        .003
    dy (m)                 -3148.991        .006
    dz (m)                 -4529.088        .005
  trop (%)                      .000        .000
bias 1 (cycle)           9588533.000        .000
bias 2 (cycle)           7281643.000        .000
bias 3 (cycle)          -1603291.000        .000
bias 4 (cycle)           4361315.000        .000
bias 5 (cycle)           7690266.000        .000
bias 6 (cycle)           9590043.000        .000
bias 7 (cycle)                  .000        .000
Rdop(norm to 60 sec) is       .295 (m/cycle)

All Baseline Vectors:
                      dx(m)         dy(m)         dz(m)        dist(m)       dh(m)

From  1 To  2    -2955.220     -3148.991     -4529.088     6257.964     -14.914

  Interval between epochs (sec)  15.0
  Epoch increment       1
  Number of measurements used in solution      30
  Number of measurements rejected               0
  RMS (cycles)         .039
```

Figure E-17. (Sheet 3 of 4)

```
 Elevation mask (deg)     15.0
 Edit multiplier    3.5
 Modified Hopfield troposphere model used

Best tracking C/A code positions
Station  1
Pdop         2.4
  x (m)          -186.448       lat  (dms)  N    34     59   52.57129
  y (m)     -5230628.653       elon (dms)  E   269     59   52.64760
  z (m)      3637728.748       wlon (dms)  W    90      0    7.35241
                               ht (m)             86.0759
clock offset(s)              .50214212D-03
freq  offset(s/s)            .70699674D-09

 Code calibration(m)      Carrier calibration(m)
0 -  1           .1860                    .0003
0 -  2         -.0625                   -.0004
0 -  3         -.3057                   -.0005
0 -  4         -.2056                   -.0004
0 -  5        -2.9268                    .0000
0 -  6        -3.0786                   -.0001
0 -  7        -3.0503                   -.0005
0 -  8        -3.0967                   -.0006
0 -  9        -3.0073                   -.0005
Station  2
Pdop         2.5
  x (m)         -3142.263       lat  (dms)  N    34     56   53.56441
  y (m)     -5233776.319       elon (dms)  E   269     57   56.16241
  z (m)      3633199.073       wlon (dms)  W    90      2    3.83759
                               ht (m)             69.7407
clock offset(s)              .54571078D-03
freq  offset(s/s)          -.13415415D-09

 Code calibration(m)      Carrier calibration(m)
0 -  1           .0161                   -.0000
0 -  2         -.0752                   -.0004
0 -  3         -.0518                   -.0002
0 -  4         -.0840                   -.0005
0 -  5         -.1821                   -.0001
0 -  6         -.0806                    .0002
0 -  7         -.0786                   -.0003
0 -  8         -.0518                   -.0009
0 -  9         -.1606                   -.0009
```

Figure E-17. (Sheet 4 of 4)

Table E-1
Repeat Baseline Comparison

File Name	dX	dY	dZ
95111791.FIX	-1564.664	-1813.619	-2636.200
52111795.k01	-1564.666	-1813.590	-2636.214
Diff in meters	0.002	0.029	0.014
Diff in ppm	1.3	16.0	5.3
98111791.FIX	1757.126	1332.128	1902.257
52111798.k01	1757.113	1332.164	1902.226
Diff in meters	0.013	0.036	0.031
Diff in ppm	7.4	27.0	16.3
52131795.k01	-3572.835	-2316.710	-3359.378
52131805.k01	-3572.853	-2316.729	-3359.378
Diff in meters	0.018	0.050	0.029
Diff in ppm	5.0	21.6	8.6
52131795.k01	-251.058	829.025	1179.100
52131808.k01	-251.061	829.020	1179.111
Diff in meters	0.003	0.005	0.011
Diff in ppm	11.9	6.0	9.3

E-6. Adjustments

GEOLAB adjustment software was used to adjust this example survey. An IOB file was created by adding processed static and kinematic baselines from data obtained on days 179 and 180. Three separate network adjustments were performed using this file.

a. The first adjustment was run holding only USC&GS HUDGINS fixed in three dimensions. This adjustment provided a check of the internal precision of the GPS observations. A partial listing of the output for adjustment one is shown in Figure E-18. The data indicated the following:

(1) As shown on page 1 of the GEOLAB adjustment, the number of redundant measurements, or degrees of freedom, within the adjustment was high (87).

(2) As shown on page 31, the 2D and 1D station major semi-axis and minor semi-axis were at or less than the few-centimeter level.

(3) As shown on pages 32 and 33, the 2D and 1D relative error ellipses between survey points were at or less than the few-centimeter level. The precision of all baselines within the adjustment exceeded 30 ppm and 87 percent exceeded 10 ppm.

(4) As shown on page 28, the histogram indicates some of the residuals were higher than anticipated. These higher residuals fell outside of the bell-shaped curve.

(5) As shown on page 29, the estimated variance factor in the statistics summary is somewhat high. Higher residuals and variance factors than seen with static data can be expected when adjusting stop-and-go baselines. Although some high residual values exist in the adjustment, the precision of all baselines relative to their length are within Second-Order Class II requirements and 87 percent are within First-Order requirements. Longer occupation times may help to improve some of the statistical values and baseline precisions if higher orders of accuracy are desired.

b. The second adjustment was run holding USC&GS HUDGINS fixed in three dimensions and P-13-2-89 fixed in two dimensions. This adjustment was performed to obtain the final adjusted horizontal positions of all of the photo control points occupied using GPS. After obtaining the adjusted positions from GEOLAB, terrestrial traverse computations were performed to obtain positions on the remaining photo control points. A partial listing of the output for adjustment two is shown in Figure E-19. Here, the statistical values and relative errors increased only slightly compared to adjustment one after holding a second point fixed. The relative precision of all baselines in the adjustment still exceed Second Order Class II requirements.

c. The third and final adjustment was ran holding USC&GS HUDGINS fixed in three dimensions and S 22 1974, HL-1 and HL-20 fixed in one dimension. All heights fixed in the adjustment were orthometric or relative to the geoid. If elevations relative to the geoid are desired, a separate vertical adjustment is required holding only one point fixed horizontally. Horizontal and vertical adjustments should not be combined because precisions in the horizontal plane will affect precisions in the vertical plane and vice versa. A partial listing of the output for adjustment three is shown in Figure E-20. Page 33 of the output indicates that the 1D confidence region for each station in the adjustment is less than 0.1 m.

E-7. Project Summary

Positions in 3D were developed for 23 photo control points as well as 2D positions for two new Type A monuments.

a. The field work for the survey was completed in approximately 35 hr with a task breakdown as follows.

(1) 8 hr for presurvey reconnaissance, 2-man crew.

```
U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A= 6378137.000 B= 6356752.314 XO= 0.000 YO= 0.000 ZO= 0.000

PREPARE:

09:34:43 - Tuesday, October 09, 1990

Input from:   <GPS7K_1.iob>
Output to:    <GPS7K_1.LST>

PREPARE successfully completed.

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```

U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A= 6378137.000 B= 6356752.314 XO= 0.000 YO= 0.000 ZO= 0.000

GETUP:

PARAMETERS		OBSERVATIONS	
Description	Number	Description	Number
All Stations	24	Directions	0
Fixed Stations	1	Distances	0
Free 3-D Stations	23	Azimuths	0
Free 2-D Stations	0	Vertical Angles	0
Free 1-D Stations	0	Zenithal Angles	0
Coord. Parameters	69	Angles	0
Astro. Latitudes	0	Heights	0
Astro. Longitudes	0	Height Differences	0
Geoid Records	0	Auxiliary Params.	0
All Aux. Pars.	0	2-D Coords.	0
Direction Pars.	0	2-D Coord. Diffs.	0
Scale Parameters	0	3-D Coords.	0
Constant Pars.	0	3-D Coord. Diffs.	156
Rotation Pars.	0		
Translation Pars.	0		
Total Parameters	69	Total Observations	156
Degrees of Freedom = 87			

```
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```

Figure E-18. Minimally constrained horizontal adjustment (Sheet 1 of 6)

U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY

A= 6378137.000 B= 6356752.314 XO= 0.000 YO= 0.000 ZO= 0.000

RESID:

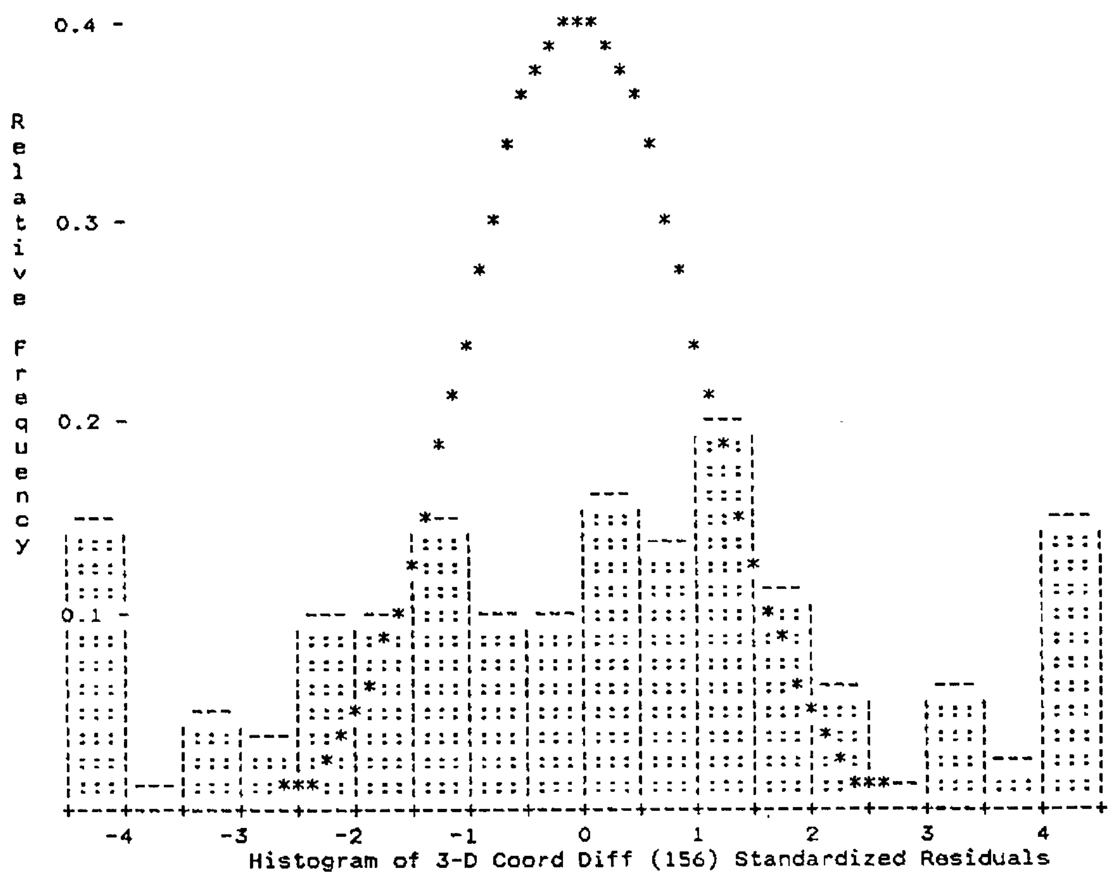

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Figure E-18. (Sheet 2 of 6)

```
-------------------------------------------------------------------------------
                  U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
              HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A=  6378137.000 B=  6356752.314 XO=        0.000 YO=        0.000 ZO=        0.000
-------------------------------------------------------------------------------
RESID:


 ------------------------------------------------------------------------------
 |                                                                            |
 |                 S T A T I S T I C S     S U M M A R Y                      |
 |                                                                            |
 |----------------------------------------------------------------------------|
 |                                      |                                     |
 |     Residual Critical Value Type     |              Tau Max                |
 |     Residual Critical Value          |               3.6542                |
 |     Convergence Criterion            |             0.001000                |
 |     Final Iteration Counter Value    |                    2                |
 |     Confidence Level Used            |              95.0000                |
 |     Number of Flagged Residuals      |                   29                |
 |     Estimated Variance Factor        |               9.2151                |
 |     Number of Degrees of Freedom     |                   87                |
 |                                      |                                     |
 |----------------------------------------------------------------------------|
 |                                                                            |
 |                Chi-Square Test on the Variance Factor:                     |
 |                                                                            |
 |                6.9901e+000  <  1.0000  <  1.2708e+001  ?                   |
 |                                                                            |
 |                                                                            |
 |    !!!!!!!!!!!!!!!!!!!!!!!!   THE TEST FAILS   !!!!!!!!!!!!!!!!!!!!!!!!    |
 |                                                                            |
 ------------------------------------------------------------------------------

RESID successfully completed.
```

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-------------------------------------------------------------------------------
GeoLab - V1.91S, (C) 1985/86/87/88/89 BitWise Ideas Inc. [103208976]  Page   29
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Figure E-18. (Sheet 3 of 6)

U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A= 6378137.000 B= 6356752.314 XO= 0.000 YO= 0.000 ZO= 0.000

ELLIPSE:

2-D AND 1-D STATION CONFIDENCE REGIONS (95.000 %):

IDENT.	MAJOR SEMI-AXIS	MINOR SEMI-AXIS	AZ(MAJ)	VERTICAL
4098	0.0037	0.0030	145.07	0.0084
4097	0.0111	0.0098	104.55	0.0231
5211	0.0086	0.0079	76.51	0.0167
5221	0.0229	0.0137	4.04	0.0536
5208	0.0353	0.0135	1.88	0.0593
5213	0.0079	0.0059	114.15	0.0117
2099	0.0190	0.0128	23.44	0.0402
5212	0.0227	0.0085	9.19	0.0985
5214	0.0139	0.0078	153.79	0.0406
5215	0.0076	0.0055	160.93	0.0217
5216	0.0056	0.0035	157.21	0.0196
5217	0.0152	0.0107	143.90	0.0344
5219	0.0167	0.0103	11.22	0.0322
5220	0.0143	0.0096	17.16	0.0295
7212	0.0102	0.0073	24.15	0.0219
5222	0.0069	0.0057	87.95	0.0139
5224	0.0150	0.0122	94.27	0.0321
5223	0.0078	0.0063	101.33	0.0176
5209	0.0074	0.0060	66.59	0.0113
5218	0.0123	0.0097	128.12	0.0201
5206	0.0116	0.0086	142.23	0.0263
5201	0.0125	0.0082	28.16	0.0260
5203	0.0115	0.0044	8.95	0.0540

GeoLab - V1.91S, (C) 1985/86/87/88/89 BitWise Ideas Inc. [103208976] Page 31

Figure E-18. (Sheet 4 of 6)

U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A= 6378137.000 B= 6356752.314 XO= 0.000 YO= 0.000 ZO= 0.000

ELLIPSE:

2-D AND 1-D RELATIVE STATION CONFIDENCE REGIONS (95.000 %):

FROM	TO	MAJ.SEMI	MIN.SEMI	AZ(MAJ)	VERTICAL	SPATIAL DIST.	PRECISION
4098	4097	0.0110	0.0097	99.22	0.0227	366.6975	29.965 PPM
4098	5211	0.0082	0.0071	72.51	0.0145	2912.1464	2.824 PPM
4098	5221	0.0231	0.0140	3.76	0.0541	4613.1049	5.003 PPM
4098	5208	0.0353	0.0132	1.93	0.0591	2733.5199	12.901 PPM
4098	2099	0.0188	0.0124	23.86	0.0395	2209.5900	8.528 PPM
4098	5212	0.0226	0.0081	9.40	0.0983	2184.0854	10.334 PPM
4098	5214	0.0140	0.0078	153.61	0.0398	1476.6279	9.461 PPM
4098	5215	0.0079	0.0057	158.56	0.0214	801.5978	9.828 PPM
4098	5216	0.0060	0.0039	154.86	0.0183	542.8320	10.996 PPM
4098	5217	0.0151	0.0106	143.88	0.0340	661.3902	22.792 PPM
4098	5219	0.0168	0.0104	11.02	0.0324	2891.5861	5.799 PPM
4098	5220	0.0139	0.0091	18.11	0.0286	2566.7333	5.434 PPM
4098	7212	0.0097	0.0064	26.24	0.0204	2016.1771	4.824 PPM
4098	5222	0.0070	0.0059	89.23	0.0142	4430.4221	1.574 PPM
4098	5224	0.0150	0.0122	94.28	0.0321	5477.8680	2.742 PPM
4098	5213	0.0076	0.0056	114.08	0.0113	1463.0776	5.162 PPM
4098	5223	0.0080	0.0065	102.72	0.0180	5905.2055	1.354 PPM
4098	5209	0.0078	0.0067	68.72	0.0132	2151.8382	3.631 PPM
4098	5218	0.0119	0.0094	127.14	0.0189	1886.0709	6.326 PPM
4098	5206	0.0118	0.0088	142.32	0.0268	3467.4965	3.412 PPM
4098	5203	0.0114	0.0041	9.23	0.0538	5895.6948	1.932 PPM
4098	5201	0.0127	0.0084	27.81	0.0264	6501.9484	1.947 PPM
4098	3095	0.0037	0.0030	145.07	0.0084	6444.1890	0.580 PPM
4097	3095	0.0111	0.0098	104.55	0.0231	6257.9628	1.776 PPM
3095	5211	0.0086	0.0079	76.51	0.0167	3561.8762	2.428 PPM
3095	5208	0.0353	0.0135	1.88	0.0593	3860.2180	9.155 PPM
3095	5221	0.0229	0.0137	4.04	0.0536	2049.7519	11.170 PPM
3095	5213	0.0079	0.0059	114.15	0.0117	5423.8080	1.456 PPM
3095	2099	0.0190	0.0128	23.44	0.0402	6228.3592	3.056 PPM
3095	5212	0.0227	0.0085	9.19	0.0985	4670.3247	4.871 PPM
3095	5214	0.0139	0.0078	153.79	0.0406	5123.7279	2.718 PPM
3095	5215	0.0076	0.0055	160.93	0.0217	6286.9779	1.201 PPM
3095	5216	0.0056	0.0035	157.21	0.0196	6093.8864	0.915 PPM
3095	5217	0.0152	0.0107	143.90	0.0344	6657.5099	2.288 PPM
3095	5219	0.0167	0.0103	11.22	0.0322	3553.0160	4.696 PPM
3095	5220	0.0143	0.0096	17.16	0.0295	4130.2034	3.452 PPM
3095	7212	0.0102	0.0073	24.15	0.0219	5986.6100	1.705 PPM
3095	5222	0.0069	0.0057	87.95	0.0139	2948.5824	2.328 PPM
3095	5224	0.0150	0.0122	94.27	0.0321	2553.4890	5.881 PPM
3095	5223	0.0078	0.0063	101.33	0.0176	1964.3998	3.985 PPM
3095	5209	0.0074	0.0060	66.59	0.0113	4497.4302	1.649 PPM
3095	5218	0.0123	0.0097	128.12	0.0201	4558.2365	2.702 PPM
3095	5206	0.0116	0.0086	142.23	0.0263	4289.4530	2.703 PPM
3095	5201	0.0125	0.0082	28.16	0.0260	7706.4120	1.628 PPM

GeoLab - V1.91S, (C) 1985/86/87/88/89 BitWise Ideas Inc. [103208976] Page 32

Figure E-18. (Sheet 5 of 6)

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U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A=  6378137.000 B=  6356752.314 XO=        0.000 YO=        0.000 ZO=        0.000
-----------------------------------------------------------------------------------
ELLIPSE:

2-D AND 1-D RELATIVE STATION CONFIDENCE REGIONS ( 95.000 %):
--------------------------------------------------------------
FROM     TO        MAJ.SEMI MIN.SEMI AZ(MAJ) VERTICAL SPATIAL DIST.   PRECISION
-------- -------- -------- -------- ------- -------- ------------- -----------
3095     5203       0.0115   0.0044    8.95   0.0540     6734.0519   1.709 PPM

ELLIPSE successfully completed.
09:40:34 - Tuesday, October 09, 1990

-----------------------------------------------------------------------------------
GeoLab - V1.91S, (C) 1985/86/87/88/89 BitWise Ideas Inc. [103208976]  Page   33
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Figure E-18. (Sheet 6 of 6)

```
U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A= 6378137.000 B= 6356752.314 XO=        0.000 YO=        0.000 ZO=        0.000

PREPARE:

10:00:35 - Tuesday, October 09, 1990

Input from:    <GPS7K_2.iob>
Output to:     <GPS7K_2.LST>

PREPARE successfully completed.

GeoLab - V1.91S, (C) 1985/86/87/88/89 BitWise Ideas Inc. [103208976]  Page    0

U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A= 6378137.000 B= 6356752.314 XO=        0.000 YO=        0.000 ZO=        0.000

GETUP:
```

PARAMETERS		OBSERVATIONS	
Description	Number	Description	Number
All Stations	24	Directions	0
Fixed Stations	1	Distances	0
Free 3-D Stations	23	Azimuths	0
Free 2-D Stations	0	Vertical Angles	0
Free 1-D Stations	0	Zenithal Angles	0
Coord. Parameters	69	Angles	0
Astro. Latitudes	0	Heights	0
Astro. Longitudes	0	Height Differences	0
Geoid Records	0	Auxiliary Params.	0
All Aux. Pars.	0	2-D Coords.	2
Direction Pars.	0	2-D Coord. Diffs.	0
Scale Parameters	0	3-D Coords.	0
Constant Pars.	0	3-D Coord. Diffs.	156
Rotation Pars.	0		
Translation Pars.	0		
Total Parameters	69	Total Observations	158
Degrees of Freedom = 89			

```
GeoLab - V1.91S, (C) 1985/86/87/88/89 BitWise Ideas Inc. [103208976]  Page    1
```

Figure E-19. Fully constrained horizontal adjustment (Sheet 1 of 6)

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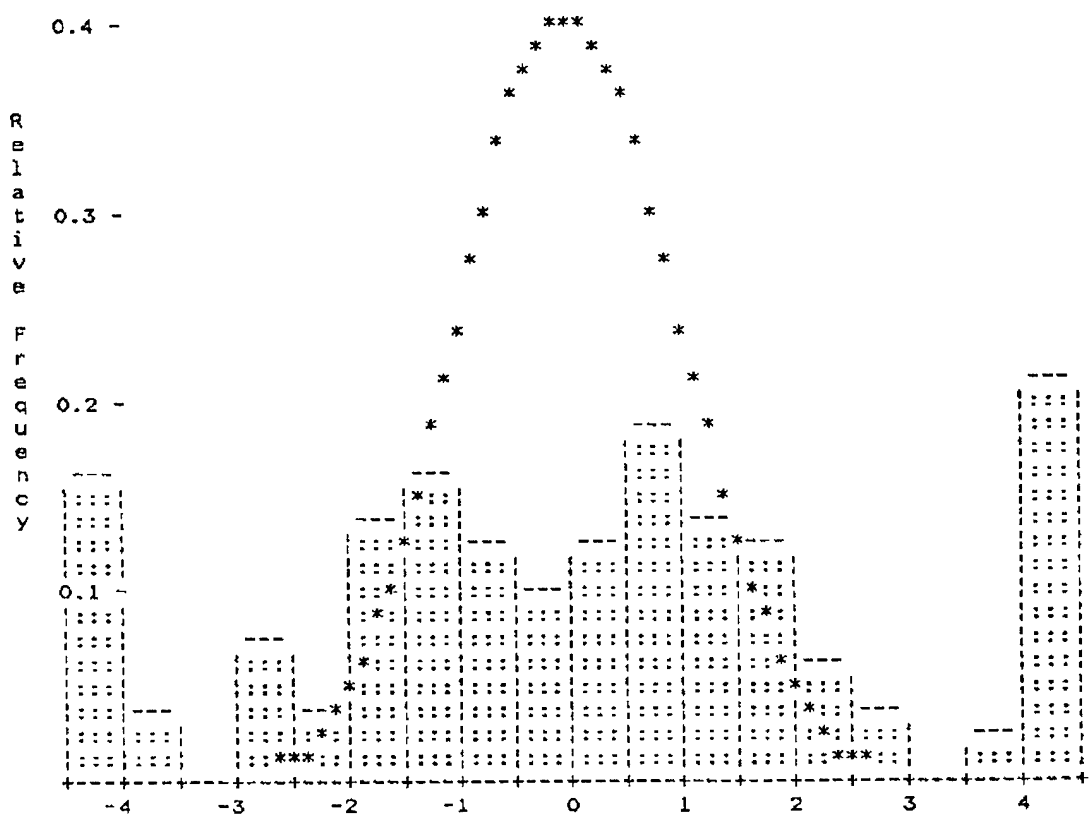
-----------------------------------------------------------------------------
              U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
      HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A=  6378137.000 B=  6356752.314 XO=        0.000 YO=         0.000 ZO=        0.000
-----------------------------------------------------------------------------
RESID:
```



Histogram of All (158) Standardized Residuals.

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-----------------------------------------------------------------------------
GeoLab - V1.91S, (C) 1985/86/87/88/89 BitWise Ideas Inc. [103208976]  Page   30
```

Figure E-19. (Sheet 2 of 6)

```
U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A= 6378137.000 B= 6356752.314 XO=       0.000 YO=       0.000 ZO=       0.000

RESID:

STATISTICS   SUMMARY

Residual Critical Value Type        Tau Max
Residual Critical Value             3.6597
Convergence Criterion               0.001000
Final Iteration Counter Value       2
Confidence Level Used               95.0000
Number of Flagged Residuals         35
Estimated Variance Factor           13.2102
Number of Degrees of Freedom        89

Chi-Square Test on the Variance Factor:

1.0050e+001  <  1.0000  <  1.8146e+001  ?

!!!!!!!!!!!!!!!!!!!!!!!!!   THE TEST FAILS   !!!!!!!!!!!!!!!!!!!!!!!!!

RESID successfully completed.

GeoLab - V1.91S, (C) 1985/86/87/88/89 BitWise Ideas Inc. [103208976]  Page  31
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Figure E-19. (Sheet 3 of 6)

U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

ELLIPSE:

2-D AND 1-D STATION CONFIDENCE REGIONS (95.000 %):

IDENT.	MAJOR SEMI-AXIS	MINOR SEMI-AXIS	AZ(MAJ)	VERTICAL
4098	0.0040	0.0034	145.07	0.0099
4097	0.0133	0.0117	103.56	0.0276
5211	0.0103	0.0093	74.85	0.0199
5221	0.0274	0.0165	4.04	0.0642
5208	0.0423	0.0161	1.90	0.0710
5213	0.0094	0.0070	113.66	0.0140
2099	0.0228	0.0152	23.58	0.0481
5212	0.0272	0.0101	9.26	0.1179
5214	0.0167	0.0093	153.80	0.0486
5215	0.0090	0.0065	160.93	0.0259
5216	0.0066	0.0042	157.23	0.0235
5217	0.0182	0.0128	143.89	0.0411
5219	0.0200	0.0123	11.25	0.0385
5220	0.0170	0.0114	17.47	0.0353
7212	0.0121	0.0085	24.83	0.0262
5222	0.0082	0.0068	87.45	0.0166
5224	0.0180	0.0146	94.13	0.0385
5223	0.0093	0.0075	101.03	0.0210
5209	0.0089	0.0072	66.56	0.0136
5218	0.0147	0.0116	127.81	0.0241
5206	0.0139	0.0103	142.23	0.0315
5201	0.0150	0.0098	28.21	0.0311
5203	0.0137	0.0052	9.10	0.0646

GeoLab - V1.91S, (C) 1985/86/87/88/89 BitWise Ideas Inc. [103208976] Page 33

Figure E-19. (Sheet 4 of 6)

U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A= 6378137.000 B= 6356752.314 XO= 0.000 YO= 0.000 ZO= 0.000

ELLIPSE:

2-D AND 1-D RELATIVE STATION CONFIDENCE REGIONS (95.000 %):

FROM	TO	MAJ.SEMI	MIN.SEMI	AZ(MAJ)	VERTICAL	SPATIAL DIST.	PRECISION
4098	4097	0.0131	0.0116	99.26	0.0271	366.6987	35.831 PPM
4098	5211	0.0098	0.0085	72.49	0.0174	2912.1468	3.381 PPM
4098	5221	0.0276	0.0167	3.85	0.0647	4613.1075	5.981 PPM
4098	5208	0.0422	0.0159	1.94	0.0707	2733.5206	15.445 PPM
4098	2099	0.0226	0.0149	23.87	0.0473	2209.5901	10.210 PPM
4098	5212	0.0270	0.0096	9.41	0.1176	2184.0857	12.372 PPM
4098	5214	0.0167	0.0093	153.65	0.0477	1476.6292	11.304 PPM
4098	5215	0.0093	0.0068	159.03	0.0256	801.5979	11.644 PPM
4098	5216	0.0070	0.0045	155.32	0.0219	542.8330	12.936 PPM
4098	5217	0.0180	0.0127	143.88	0.0407	661.3897	27.271 PPM
4098	5219	0.0200	0.0124	11.12	0.0388	2891.5879	6.933 PPM
4098	5220	0.0167	0.0109	18.11	0.0342	2566.7336	6.506 PPM
4098	7212	0.0116	0.0077	26.24	0.0244	2016.1771	5.776 PPM
4098	5222	0.0083	0.0070	88.31	0.0170	4430.4238	1.873 PPM
4098	5224	0.0180	0.0146	94.14	0.0385	5477.8695	3.280 PPM
4098	5213	0.0090	0.0067	113.86	0.0135	1463.0782	6.169 PPM
4098	5223	0.0095	0.0077	101.99	0.0215	5905.2073	1.611 PPM
4098	5209	0.0093	0.0078	67.94	0.0157	2151.8403	4.314 PPM
4098	5218	0.0143	0.0112	127.13	0.0226	1886.0714	7.572 PPM
4098	5206	0.0141	0.0105	142.28	0.0321	3467.4980	4.065 PPM
4098	5203	0.0136	0.0049	9.29	0.0644	5895.6951	2.311 PPM
4098	5201	0.0151	0.0100	27.97	0.0315	6501.9487	2.326 PPM
4098	3095	0.0040	0.0034	145.07	0.0099	6444.1920	0.620 PPM
4097	3095	0.0133	0.0117	103.56	0.0276	6257.9643	2.119 PPM
3095	5211	0.0103	0.0093	74.85	0.0199	3561.8789	2.885 PPM
3095	5208	0.0423	0.0161	1.90	0.0710	3860.2203	10.956 PPM
3095	5221	0.0274	0.0165	4.04	0.0642	2049.7523	13.373 PPM
3095	5213	0.0094	0.0070	113.66	0.0140	5423.8102	1.726 PPM
3095	2099	0.0228	0.0152	23.58	0.0481	6228.3617	3.653 PPM
3095	5212	0.0272	0.0101	9.26	0.1179	4670.3272	5.823 PPM
3095	5214	0.0167	0.0093	153.80	0.0486	5123.7294	3.250 PPM
3095	5215	0.0090	0.0065	160.93	0.0259	6286.9790	1.435 PPM
3095	5216	0.0066	0.0042	157.23	0.0235	6093.8876	1.090 PPM
3095	5217	0.0182	0.0128	143.89	0.0411	6657.5119	2.732 PPM
3095	5219	0.0200	0.0123	11.25	0.0385	3553.0171	5.620 PPM
3095	5220	0.0170	0.0114	17.47	0.0353	4130.2059	4.118 PPM
3095	7212	0.0121	0.0085	24.83	0.0262	5986.6129	2.026 PPM
3095	5222	0.0082	0.0068	87.45	0.0166	2948.5833	2.778 PPM
3095	5224	0.0180	0.0146	94.13	0.0385	2553.4896	7.035 PPM
3095	5223	0.0093	0.0075	101.03	0.0210	1964.4001	4.759 PPM
3095	5209	0.0089	0.0072	66.56	0.0136	4497.4308	1.974 PPM
3095	5218	0.0147	0.0116	127.81	0.0241	4558.2390	3.215 PPM
3095	5206	0.0139	0.0103	142.23	0.0315	4289.4539	3.234 PPM
3095	5201	0.0150	0.0098	28.21	0.0311	7706.4128	1.948 PPM

GeoLab - V1.91S, (C) 1985/86/87/88/89 BitWise Ideas Inc. [103208976] Page 34

Figure E-19. (Sheet 5 of 6)

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-----------------------------------------------------------------------------
              U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
        HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A=  6378137.000 B=  6356752.314 XO=        0.000 YO=        0.000 ZO=        0.000
-----------------------------------------------------------------------------
ELLIPSE:

2-D AND 1-D RELATIVE STATION CONFIDENCE REGIONS ( 95.000 %):
------------------------------------------------------------------
FROM     TO       MAJ.SEMI MIN.SEMI AZ(MAJ) VERTICAL SPATIAL DIST.   PRECISION
-------- -------- -------- -------- ------- -------- -------------  ------------
3095     5203       0.0137   0.0052    9.10   0.0646     6734.0532   2.040 PPM

ELLIPSE successfully completed.
10:06:34 - Tuesday, October 09, 1990
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GeoLab - V1.91S, (C) 1985/86/87/88/89 BitWise Ideas Inc. [103208976]  Page   35
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Figure E-19. (Sheet 6 of 6)

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U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A= 6378137.000 B= 6356752.314 XO= 0.000 YO= 0.000 ZO= 0.000

PREPARE:

10:29:30 - Tuesday, October 09, 1990

Input from: <GPS7K_3.iob>
Output to: <GPS7K_3.LST>

PREPARE successfully completed.

GeoLab - V1.91S, (C) 1985/86/87/88/89 BitWise Ideas Inc. [103208976] Page 0
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```
U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A= 6378137.000 B= 6356752.314 XO= 0.000 YO= 0.000 ZO= 0.000

GETUP:
```

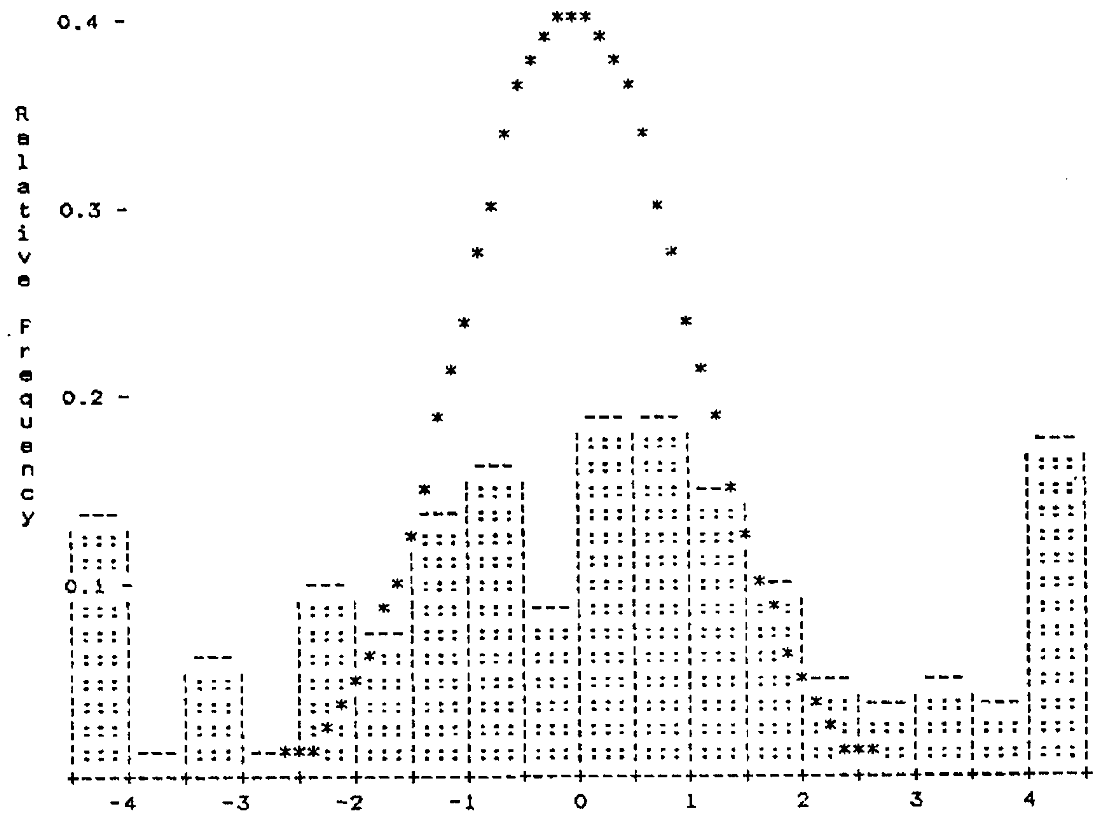
PARAMETERS		OBSERVATIONS	
Description	Number	Description	Number
All Stations	24	Directions	0
Fixed Stations	1	Distances	0
Free 3-D Stations	23	Azimuths	0
Free 2-D Stations	0	Vertical Angles	0
Free 1-D Stations	0	Zenithal Angles	0
Coord. Parameters	69	Angles	0
Astro. Latitudes	0	Heights	3
Astro. Longitudes	0	Height Differences	0
Geoid Records	0	Auxiliary Params.	0
All Aux. Pars.	0	2-D Coords.	0
Direction Pars.	0	2-D Coord. Diffs.	0
Scale Parameters	0	3-D Coords.	0
Constant Pars.	0	3-D Coord. Diffs.	156
Rotation Pars.	0		
Translation Pars.	0		
Total Parameters	69	Total Observations	159
Degrees of Freedom = 90			

```
GeoLab - V1.91S, (C) 1985/86/87/88/89 BitWise Ideas Inc. [103208976] Page 1
```

Figure E-20. Fully constrained vertical adjustment (Sheet 1 of 6)

U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A= 6378137.000 B= 6356752.314 XO= 0.000 YO= 0.000 ZO= 0.000

RESID:



Histogram of All (159) Standardized Residuals.

GeoLab - V1.91S, (C) 1985/86/87/88/89 BitWise Ideas Inc. [103208976] Page 30

Figure E-20. (Sheet 2 of 6)

```
U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A= 6378137.000 B= 6356752.314 X0=        0.000 Y0=        0.000 Z0=        0.000

RESID:


                 S T A T I S T I C S    S U M M A R Y

     Residual Critical Value Type       |           Tau Max
     Residual Critical Value            |            3.6624
     Convergence Criterion              |          0.001000
     Final Iteration Counter Value      |                 2
     Confidence Level Used              |           95.0000
     Number of Flagged Residuals        |                30
     Estimated Variance Factor          |            9.3212
     Number of Degrees of Freedom       |                90

               Chi-Square Test on the Variance Factor:

               7.1012e+000  <  1.0000  <  1.2779e+001   ?

     !!!!!!!!!!!!!!!!!!!!!!!!!   THE TEST FAILS   !!!!!!!!!!!!!!!!!!!!!!!!!

RESID successfully completed.

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Figure E-20. (Sheet 3 of 6)

U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A= 6378137.000 B= 6356752.314 XO= 0.000 YO= 0.000 ZO= 0.000

ELLIPSE:

2-D AND 1-D STATION CONFIDENCE REGIONS (95.000 %):

IDENT.	MAJOR SEMI-AXIS	MINOR SEMI-AXIS	AZ(MAJ)	VERTICAL
4098	0.0037	0.0030	144.69	0.0080
4097	0.0112	0.0099	104.44	0.0232
5211	0.0087	0.0079	76.37	0.0166
5221	0.0230	0.0138	4.04	0.0539
5208	0.0355	0.0136	1.89	0.0596
5213	0.0079	0.0060	114.13	0.0117
2099	0.0129	0.0125	134.78	0.0006
5212	0.0229	0.0086	9.20	0.0990
5214	0.0140	0.0078	153.78	0.0407
5215	0.0076	0.0055	160.87	0.0217
5216	0.0056	0.0035	157.13	0.0196
5217	0.0153	0.0108	143.89	0.0345
5219	0.0168	0.0103	11.22	0.0323
5220	0.0098	0.0087	129.60	0.0006
7212	0.0103	0.0073	24.26	0.0219
5222	0.0069	0.0058	87.89	0.0139
5224	0.0151	0.0123	94.25	0.0323
5223	0.0079	0.0063	101.29	0.0176
5209	0.0075	0.0060	66.59	0.0114
5218	0.0124	0.0098	128.06	0.0201
5206	0.0117	0.0086	142.23	0.0264
5201	0.0090	0.0082	31.01	0.0006
5203	0.0116	0.0044	8.97	0.0542

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Figure E-20. (Sheet 4 of 6)

U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

ELLIPSE:

2-D AND 1-D RELATIVE STATION CONFIDENCE REGIONS (95.000 %):

FROM	TO	MAJ.SEMI	MIN.SEMI	AZ(MAJ)	VERTICAL	SPATIAL DIST.	PRECISION
4098	4097	0.0110	0.0098	99.29	0.0228	366.6974	30.134 PPM
4098	5211	0.0083	0.0072	72.51	0.0146	2912.1465	2.841 PPM
4098	5221	0.0232	0.0141	3.77	0.0543	4613.1048	5.031 PPM
4098	5208	0.0355	0.0133	1.94	0.0594	2733.5198	12.975 PPM
4098	2099	0.0127	0.0123	153.61	0.0080	2209.5932	5.731 PPM
4098	5212	0.0227	0.0081	9.40	0.0988	2184.0853	10.393 PPM
4098	5214	0.0141	0.0078	153.61	0.0401	1476.6279	9.515 PPM
4098	5215	0.0079	0.0058	158.62	0.0215	801.5977	9.882 PPM
4098	5216	0.0060	0.0039	154.93	0.0184	542.8319	11.054 PPM
4098	5217	0.0152	0.0106	143.88	0.0342	661.3901	22.922 PPM
4098	5219	0.0169	0.0105	11.04	0.0326	2891.5859	5.832 PPM
4098	5220	0.0093	0.0084	140.18	0.0080	2566.7382	3.642 PPM
4098	7212	0.0098	0.0064	26.24	0.0205	2016.1771	4.852 PPM
4098	5222	0.0070	0.0059	89.11	0.0142	4430.4221	1.583 PPM
4098	5224	0.0151	0.0123	94.26	0.0323	5477.8680	2.758 PPM
4098	5213	0.0076	0.0056	113.97	0.0113	1463.0774	5.189 PPM
4098	5223	0.0080	0.0065	102.62	0.0180	5905.2054	1.361 PPM
4098	5209	0.0079	0.0067	68.68	0.0131	2151.8379	3.652 PPM
4098	5218	0.0120	0.0094	127.14	0.0190	1886.0709	6.362 PPM
4098	5206	0.0119	0.0088	142.30	0.0269	3467.4963	3.430 PPM
4098	5203	0.0115	0.0041	9.24	0.0541	5895.6947	1.943 PPM
4098	5201	0.0092	0.0085	23.95	0.0080	6501.9478	1.419 PPM
4098	3095	0.0037	0.0030	144.69	0.0080	6444.1888	0.579 PPM
4097	3095	0.0112	0.0099	104.44	0.0232	6257.9628	1.785 PPM
3095	5211	0.0087	0.0079	76.37	0.0166	3561.8760	2.441 PPM
3095	5208	0.0355	0.0136	1.89	0.0596	3860.2179	9.207 PPM
3095	5221	0.0230	0.0138	4.04	0.0539	2049.7519	11.234 PPM
3095	5213	0.0079	0.0060	114.13	0.0117	5423.8080	1.464 PPM
3095	2099	0.0129	0.0125	134.78	0.0006	6228.3515	2.073 PPM
3095	5212	0.0229	0.0086	9.20	0.0990	4670.3246	4.898 PPM
3095	5214	0.0140	0.0078	153.78	0.0407	5123.7278	2.733 PPM
3095	5215	0.0076	0.0055	160.87	0.0217	6286.9777	1.207 PPM
3095	5216	0.0056	0.0035	157.13	0.0196	6093.8863	0.919 PPM
3095	5217	0.0153	0.0108	143.89	0.0345	6657.5098	2.301 PPM
3095	5219	0.0168	0.0103	11.22	0.0323	3553.0159	4.723 PPM
3095	5220	0.0098	0.0087	129.60	0.0006	4130.1976	2.364 PPM
3095	7212	0.0103	0.0073	24.26	0.0219	5986.6100	1.714 PPM
3095	5222	0.0069	0.0058	87.89	0.0139	2948.5823	2.341 PPM
3095	5224	0.0151	0.0123	94.25	0.0323	2553.4888	5.915 PPM
3095	5223	0.0079	0.0063	101.29	0.0176	1964.3997	4.007 PPM
3095	5209	0.0075	0.0060	66.59	0.0114	4497.4302	1.659 PPM
3095	5218	0.0124	0.0098	128.06	0.0201	4558.2364	2.717 PPM
3095	5206	0.0117	0.0086	142.23	0.0264	4289.4530	2.719 PPM
3095	5201	0.0090	0.0082	31.01	0.0006	7706.4127	1.165 PPM

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Figure E-20. (Sheet 5 of 6)

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              U.S. ARMY CORPS OF ENGINEERS - MEMPHIS DISTRICT
        HORN LAKE CREEK PHOTO CONTROL - GPS STOP & GO KINEMATIC SURVEY
A=  6378137.000 B=  6356752.314 XO=       0.000 YO=        0.000 ZO=        0.000
--------------------------------------------------------------------------------
ELLIPSE:

2-D AND 1-D RELATIVE STATION CONFIDENCE REGIONS ( 95.000 %):
---------------------------------------------------------------------
FROM      TO         MAJ.SEMI MIN.SEMI AZ(MAJ) VERTICAL SPATIAL DIST.    PRECISION
-------- -------- -------- -------- ------- -------- ------------- -----------
3095      5203        0.0116   0.0044    8.97   0:0542      6734.0520    1.718 PPM

ELLIPSE successfully completed.
10:36:17 - Tuesday, October 09, 1990




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Figure E-20. (Sheet 6 of 6)

(2) 5 hr to set temporary photo control points and obtain visibility information at each site, 2-man crew.

(3) 2 hr to install two Type A monuments, 3-man crew.

(4) 5 hr to perform necessary Third-Order traverse and leveling, 4-man crew.

(5) 15 hr to collect static and stop-and-go GPS data, 5-man crew.

b. A conservative estimate of the field operations required by a 4-man party to 3D-position the 23 photo control points using conventional terrestrial methods was approximately 70 hr. The accuracies obtained from the final horizontal adjustment of the GPS data exceeded the requirements of the project. The accuracies obtained from the final vertical adjustment of the GPS data met the requirements.

Appendix F
Field Reduction and Adjustment of GPS Surveys

F-1. General

This appendix contains sample data reduction, adjustment, and analysis of GPS surveys. It is intended for guidance to field personnel performing field-to-finish survey work with the GPS. GPS survey data can (and should) be evaluated as soon as possible after observations are completed, preferably within 1 or 2 days. This appendix covers evaluation of internal closures, external closures, adjustment techniques, and evaluation of the adequacy of these results. A PC-based least squares adjustment package is not necessary to perform acceptable final field adjustments. Most USACE GPS work, other than baseline reductions, can be analyzed and adequately adjusted using simple hand-held calculators, as shown herein.

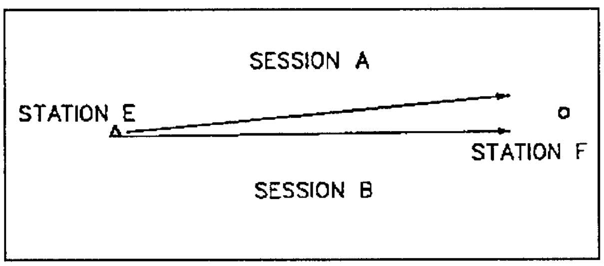

Figure F-1. Spur line adjustment

F-2. Mean Coordinate Adjustment of Spur Lines

If spur lines are observed twice between points E and F, as shown in Figure F-1, a simple mean adjustment computation is recommended. This method is applicable not only to carrier phase measurements but also code phase positioning techniques. It is important that the user determine the acceptable closure limits. This evaluation simply involves comparing the differences between multiple sessions taken over the same baseline. Alternately, a double spur line can be considered as a loop, from which the internal loop closure can be computed. Two independent baseline sessions were observed between points E and F, as shown in Table F-1.

The known geocentric coordinates of point E are:

X = 1108302.838
Y = -4856338.733
Z = 3970134.434

Computing the 3D misclosure between the vectors:

$$(0.002^2 + (-)0.002^2 + 0.001^2)^{1/2} = 0.003 \text{ m}$$

$$\text{3D vector distance} = (113.841^2 + 44.284^2 + 18.800^2)^{1/2} = 123.589 \text{ m}$$

The relative accuracy estimate between the two vectors is then:

0.003/123.589 or 1:41,200 (acceptable)

Given the acceptable check between the two observations, the vectors for the two sessions can be simply averaged. Since E is the known station, the mean vector components shown in Table F-1 can be applied to the geocentric coordinates of E to position station F.

Point E adjusted geocentric coordinates:

X = 1108302.838 + (-)113.841 = 1108188.997
Y = -4856338.733 + 44.284 = -4856294.449
Z = 3970134.434 + 18.800 = 3970153.234

Final geographic coordinates and/or SPCS coordinates of point F can then be transformed using the techniques

Table F-1
Baseline Sessions

Vector	Julian Day	Baseline Session	DX m	DY m	DZ m
E-F	135	A	-113.842	44.283	18.800
E-F	135	B	-113.840	44.285	18.799
Vector Differences			0.002	-0.002	0.001
Mean Vector Component			-113.841	44.284	18.800

given in Chapter 11. The position should be identified as a "no check" point as would be done in conventional survey practice.

F-3. Field Adjustment of GPS Triangle

This example illustrates the various methods which may be used to evaluate the internal and external accuracies of a GPS survey in the field. In addition, both an approximate and rigorous least squares adjustment are performed on the same GPS data to illustrate the small differences in results.

Multiple GPS baseline sessions are observed on the triangle ETLE-HEC2-ETLN, as shown in Figure F-2. Station ETLN is the unknown point for which coordinates are desired to an accuracy of 1 part in 10,000 (Third-Order, Class I). Stations ETLE and HEC2 are fixed, with the following geocentric (WGS 84) metric coordinates:

	X	Y	Z
HEC2	1108302.838	-4856338.733	3970134.434
ETLE	1108314.518	-4856507.916	3969923.835
Diff:	-11.680	169.183	210.599

(The above geocentric coordinates may have been computed in the field using the algorithms given in Chapter 11 on either NAD 83 or NAD 27 datums)

Observed and mean vectors from the baseline reductions are shown in Tables F-2 and F-3.

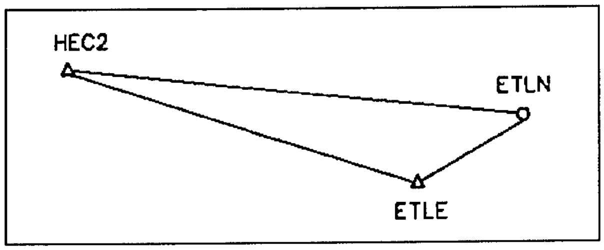

Figure F-2. GPS triangle vector adjustment

F-4. Internal GPS Loop Closure Check

A loop closure check is performed by arbitrarily letting one set of coordinates equal to zero, then algebraically adding vector components around the loop back to the initial point. Care must be taken in applying the correct vector signs based on the observed vector direction.

Letting station ETLE be fixed (X = Y = Z = 0), and using Session A for line ETLE-HEC2 and ETLE-ETLN and Session B for line ETLN-HEC2, and proceeding counter-clockwise around the loop:

$$\Delta x = 98.418 + (-110.083) + (-)(-11.676) = +0.011 \text{ m}$$

$$\Delta y = 9.929 + (-)(-159.250) + (-)169.179 = 0.000 \text{ m}$$

Table F-2
Observed Vectors from Sessions A and B

Vector	Session	dx	dy	dz
ETLE-ETLN	A	98.418	9.929	-30.837
ETLE-HEC2	A	-11.676	169.179	210.612
ETLN-HEC2	A	-110.094	159.251	241.448
ETLE-ETLN	B	98.405	9.932	-30.834
ETLE-HEC2	B	-11.676	169.184	210.602
ETLN-HEC2	B	-110.083	159.250	241.444

Table F-3
Mean Vector Components for Sessions A and B

Mean Vector	dx	dy	dz	Distance
ETLE-ETLN	98.412	9.930	-30.836	103.607
ETLE-HEC2	-11.676	169.182	210.607	270.396
ETLN-HEC2	-110.089	159.251	241.446	309.478

Δz = -30.837 +(-)(-241.444) + (-)210.612 = (-)0.005 m

(Note that any sequence of session vectors could have been used to perform this check)

Linear 3D closure = $(0.011^2 + 0.000^2 + -0.005^2)^{1/2}$
= 0.012 m

3D vector distance = (103.607 + 270.396 + 309.478)
= 683.5 m

Where the individual vector distances were computed by taking the square of the sum of the squares of the component vectors.

The relative accuracy estimate of the loop closure is then:

0.012/683.5 or 1:57,000 (acceptable)

This relative accuracy estimate (1 part in 57,000) is based on the internal loop closure results, and indicates that the basic GPS observations are acceptable for subsequent constrained adjustment of station ETLN in the fixed network of HEC2 and ETLE.

F-5. Verification of GPS Distances Over Fixed Baselines

The following computation checks the adequacy of the GPS observations over the existing fixed network, i.e., between HEC2 and ETLE. Computing the difference between the mean session vector (from Table F-3) and true vector components over the fixed baseline between ETLE and HEC2:

Delta X = -11.676 - -11.680 = 0.004
Delta Y = 169.182 - 169.183 = -0.001
Delta Z = 210.607 - 210.599 = 0.008

The linear misclosure over the baseline is then checked relative to the length of the line:

Linear 3D closure = $(0.004^2 + 0.001^2 + 0.008^2)^{1/2}$
= 0.009 m

The relative accuracy estimate of the baseline closure is then:

0.009/270.4 or 1:30,000 (OK)

This indicates that the observed baseline vector agrees with the fixed control scheme on the order of 1 part in 30,000. Had this check been poor--say only 1 part in 2,500--this would more than likely indicate a problem with the fixed control network, given the excellent internal loop closures obtained. In such instances, additional fixed control points would have to be connected.

F-6. External Closure Verification (GPS Traverse)

This computation illustrates the process for checking the external closure on a GPS traverse run from ETLE to ETLN, and closing on HEC2 (i.e., vector ETLE-ETLN (Session A) and vector ETLN-HEC2 (Session B)). The GPS traverse vectors (Figure F-3) are summed forward as described previously.

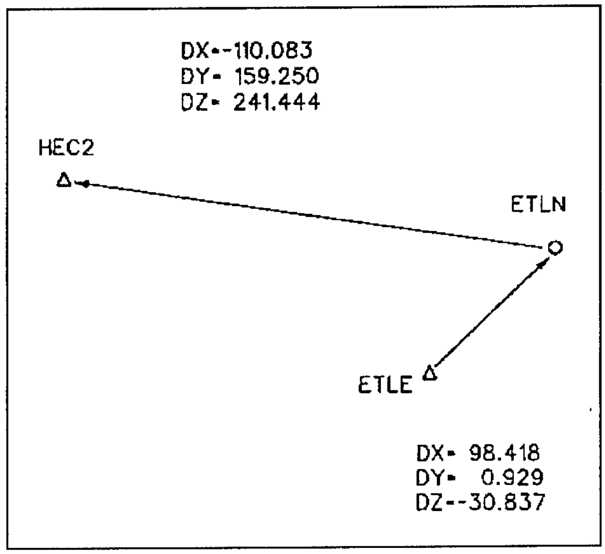

Figure F-3. External traverse closure checks

X_{HEC2} = 1108314.518 + 98.418 +(-110.083)
= 1108302.853

Y_{HEC2} = -4856507.916 + 9.929 + 159.250
= -4856338.737

Z_{HEC2} = 3969923.835 +(-30.837) + 241.444
= 3970134.442

Comparing the difference between these computed points and the fixed (i.e., published) points for HEC2:

ΔX = measured/computed coordinate - true coordinate

= 1108302.853 - 1108302.838 = 0.015 m

ΔY = -4856338.737 - (-4856338.733) = (-) 0.004 m

ΔZ = 3970134.442 - 3970134.434 = 0.008 m

The linear misclosure at the traverse closing point (HEC2) then checked relative to the total length of the traverse. This is performed similarly to conventional traverses except that three dimensions and no azimuth misclosures are involved:

$$\text{Linear 3D closure} = (0.015^2 + 0.004^2 + 0.008^2)^{1/2} = 0.017 \text{ m}$$

3D traverse length = 103.6 + 309.5 = 413.1 m

The relative accuracy estimate of the absolute (external) traverse closure is then:

0.017/413.1 or 1:24,000 (OK)

This result is consistent with the previous check over the fixed baseline ETLE-HEC2 and the internal loop closure results. (In practice, GPS traverses will have more legs than this example, and a GPS observation may not have been made between fixed network points.)

The misclosures at HEC2 could be balanced over the two traverse legs using one of the traverse balancing methods given in Chapter 11. From this, the adjusted coordinates of ETLN could be obtained. Since this involves more computation, the simple mean adjustment method in paragraph F-7 is more practical.

F-7. Approximate Adjustment of ETLN Using Mean Coordinate Values

The coordinates of station ETLN are then computed by finding the mean of the coordinates as computed forward from each fixed station, using the mean vectors in Table F-3:

$$X_{ETLN}\,(1) = X_{ETLE} + dx_{ETLE\text{-}ETLN} = 1108314.518 + 98.412 = 1108412.930$$

$$X_{ETLN}\,(2) = X_{HEC2} + dx_{HEC2\text{-}ETLN} = 1108302.838 + 110.089 = 1108412.927$$

(Note the sign of the vector HEC2-ETLN is reversed from that observed -- ETLN-HEC2)

Given the small X-coordinate difference (3 mm), a simple mean adjustment is justified, as opposed to a more rigorous and time-consuming least squares adjustment.

$$\text{Mean } X_{ETLN} = [\, X_{ETLE}\,(1) + X_{ETLE}\,(2)\,] / 2 = [\, 1108412.930 + 1108412.927\,] / 2 = 1108412.928$$

The averaged Y and Z coordinates of ETLN are also computed in a manner similar to that for the X:

$$\text{Mean } Y_{ETLN} = -4856497.985$$

$$\text{Mean } Z_{ETLN} = 3969892.994$$

F-8. Least Squares Adjustment Using FILLNET

To compare the results of this approximate mean adjustment with a least squares solution, all baseline observations from Sessions A and B were input into FILLNET.

Each GPS baseline was given equal relative weighting, as shown. The output from the FILLNET adjustment is shown in Figure F-4 and includes annotations denoting significant statistics resulting from the adjustment. The resultant standard error of unit weight and normalized residuals are significantly below the nominal value of "1.0" indicating that the initial (i.e., a priori) baseline relative weighting ($\pm$5H/10V mm + 2 ppm) was somewhat high. None of the normalized residuals exceeded three times the standard error of unit weight ($\pm$1.95); thus, no observations would be rejected.

The relative line accuracy estimates all exceed 1:10,000; thus the constrained survey meets intended accuracy criteria. Since the FILLNET relative precision estimates are given at the 1-sigma level, they must be divided by 2 to relate to FGCC standards at the 2-sigma (95 percent confidence) level. Thus, the smallest ratio from ETLE to ETLN (1:24,313) is evaluated as 1:12,156 in order to assess compliance with FGCC Third-Order (I) criteria.

The resultant adjusted position of ETLN (in NAD 83 geographical coordinates) from this FILLNET run was:

Latitude: 38° 44' 26.43969"

Longitude: 77° 08' 36.34637"

These coordinates may then be transformed to X-Y-Z geocentric coordinates using the HP calculator algorithms given in Chapter 11 and then compared with the meaned values from the preceding approximate adjustment:

$$\text{L/S } X_{ETLN} = 1108412.928$$

$$\text{L/S } Y_{ETLN} = -4856497.986$$

$$\text{L/S } Z_{ETLN} = 3969893.000$$

```
PROGRAM FILLNET, Version 3.0.00
LICENSED TO: ASHTECH INC.


Fillnet Input File  jim                     38.7     77.1

a =  6378137.000    1/f =  298.2572235   W      Longitude positive WEST

PRELIMINARY COORDINATES:
                       LAT.              LON.         ELEV.    G.H.   CONSTR.

  1  FFF    ETLE 38 44 27.46754   77  8 40.41060    -7.020    0.000
  2         ETLN 38 44 26.61017   77  8 36.40653     8.066    0.000
  3  FFF    HEC2 38 44 36.19465   77  8 39.32344    -5.900    0.000

GROUP 1, NO. OF VECTORS AND BIAS CONSTRAINTS:

  6      0.000  0.001    0.000  0.000    0.000  0.000    0.000  0.000

VECTORS:
                  DX          DY          DZ        LENGTH    ERROR CODES

ETLE   ETLN     98.418       9.929     -30.837    103.613   5 52.0 102.0   3
ETLN   HEC2   -110.094     159.251     241.448    309.481   5 52.0 102.0   3
ETLE   HEC2    -11.676     169.184     210.602    270.394   5 52.0 102.0   4
ETLE   ETLN     98.405       9.932     -30.834    103.600   5 52.0 102.0   4
ETLE   HEC2    -11.676     169.184     210.602    270.394   5 52.0 102.0   4
ETLN   HEC2   -110.083     159.250     241.444    309.474   5 52.0 102.0   4

SHIFTS:
    1   0.000   0.000   0.000
    2  -5.258   1.454 -24.857
    3   0.000   0.000   0.000

ADJUSTED VECTORS, GROUP 1:
                           DX,DY,DZ    V          DN,DE,DU    v       v'

ETLE   ETLN      253 A       98.411 -0.005      -31.750  0.001     0.2
                              9.932  0.002       98.145 -0.005    -0.8
                            -30.837 -0.001       -9.689 -0.004    -0.3

ETLN   HEC2      253 A     -110.092  0.005      300.849 -0.004    -0.6
                            159.251  0.001      -71.760  0.005     0.8
                            241.436 -0.004       10.627 -0.002    -0.2

ETLE   HEC2      253 B      -11.680 -0.000      269.099  0.002     0.3
                            169.183 -0.001       26.385 -0.001    -0.1
                            210.600  0.003        0.938  0.003     0.2

ETLE   ETLN      253 B       98.411  0.008      -31.750 -0.005    -0.7
                              9.932 -0.001       98.145  0.007     1.0
                            -30.837 -0.004       -9.689 -0.001    -0.1

ETLE   HEC2      253 B      -11.680 -0.000      269.099  0.002     0.3
                            169.183 -0.001       26.385 -0.001    -0.1
                            210.600  0.003        0.938  0.003     0.2

ETLN   HEC2      253 B     -110.092 -0.006      300.849  0.001     0.2
                            159.251  0.002      -71.760 -0.006    -0.8
                            241.436 -0.000       10.627 -0.003    -0.2

S.E. OF UNIT WEIGHT =      0.593
```

Figure F-4. FILLNET least squares adjustment of ETLN (Continued)

```
NUMBER OF -
   OBS. EQUATIONS                19
   UNKNOWNS                       7
   DEGREES OF FREEDOM            12
   ITERATIONS                     0


GROUP  1 ROT. ANGLES (sec.) AND SCALE DIFF. (ppm):

HOR. SYSTEM          0.000   3.133  -2.570 -15.571
STD. ERRORS          0.001   3.618   1.807   8.762
XYZ SYSTEM           2.606   2.655  -1.607

ADJUSTED POSITIONS:

                  LAT.              LON.          ELEV.    STD. ERRORS (m)

   1  ETLE    38 44 27.46754   77  8 40.41060    -7.020 0.000 0.000 0.000
   2  ETLN    38 44 26.43966   77  8 36.34630   -16.791 0.003 0.003 0.005
   3  HEC2    38 44 36.19465   77  8 39.32344    -5.900 0.000 0.000 0.000

ACCURACIES (m):
                                 D. LAT.    D. LON.     VERT.

 ETLE           ETLN             0.003      0.003      0.005
 ETLN           HEC2             0.003      0.003      0.005
 ETLE           HEC2             0.000      0.000      0.000
 ETLE           ETLN             0.003      0.003      0.005
 ETLE           HEC2             0.000      0.000      0.000
 ETLN           HEC2             0.003      0.003      0.005


*****************************************************************
****                                                         ****
****                 ESTIMATES OF PRECISION                  ****
****                                                         ****
****        Based on the VECTOR ACCURACIES produced by       ****
****                         FILLNET                         ****
****                                                         ****
****      This is a reasonable estimate of the accuracies    ****
****        of the vectors in the network at 1 SIGMA.        ****
****                                                         ****
*****************************************************************

   VECTOR            LENGTH     PPM(h)  RATIO(h)     PPM(v)  RATIO(v)

ETLE   ETLN         103.607     41.1  1:    24313     48.3  1:    20721
ETLN   HEC2         309.471     13.7  1:    72900     16.2  1:    61894
ETLE   HEC2         270.391      0.0  1:        0      0.0  1:        0
ETLE   ETLN         103.607     41.1  1:    24313     48.3  1:    20721
ETLE   HEC2         270.391      0.0  1:        0      0.0  1:        0
ETLN   HEC2         309.471     13.7  1:    72900     16.2  1:    61894
```

Figure F-4. (Concluded)

Position differences (least squares - mean adjustments):

dX = 0.000 dY = 0.001 dZ = 0.006

Based on these results, the difference in results between a least squares and simple mean adjustment, for this case, is not significant.

If this were a survey obtained under contract, then a free adjustment would have been used to measure contract performance, not a constrained adjustment. The previous loop/line checks would have adequately served as a free adjustment in checking internal adequacy. Failure of a constrained survey adjustment to meet minimum relative accuracy standards (presuming the free adjustment did) indicates a problem with the existing network, or connections thereto.

The free adjustment of the same scheme shown in Figure F-5 illustrates the overall improvement in relative accuracy estimates over the constrained adjustments. Although the GPS vector standard errors were decreased from those used in the constrained adjustment, this will have no effect on the relative distance accuracy ratios in a free adjustment. As with the constrained adjustment, the precision ratios must be divided by 2.

```
PROGRAM FILLNET, Version 3.0.00
LICENSED TO: ASHTECH INC.


Fillnet Input File  jim                        38.7    77.1

a =  6378137.000    1/f =  298.2572235   W      Longitude positive WEST

PRELIMINARY COORDINATES:
                          LAT.                LON.          ELEV.     G.H.   CONSTR.

  1  FFF     ETLE 38 44 27.46754   77  8 40.41060     -7.020    0.000
  2          ETLN 38 44 26.61017   77  8 36.40653      8.066    0.000
  3          HEC2 38 44 36.19465   77  8 39.32344     -5.900    0.000

GROUP 1, NO. OF VECTORS AND BIAS CONSTRAINTS:

  6      0.000  0.001    0.000  0.001    0.000  0.001    0.000  0.001

VECTORS:
                       DX          DY          DZ        LENGTH   ERROR CODES

ETLE   ETLN       98.418       9.929     -30.837     103.613   5 52.0 102.0   3
ETLN   HEC2     -110.094     159.251     241.448     309.481   5 52.0 102.0   3
ETLE   HEC2      -11.676     169.184     210.602     270.394   5 52.0 102.0   4
ETLE   ETLN       98.405       9.932     -30.834     103.600   5 52.0 102.0   4
ETLE   HEC2      -11.676     169.184     210.602     270.394   5 52.0 102.0   4
ETLN   HEC2     -110.083     159.250     241.444     309.474   5 52.0 102.0   4

SHIFTS:
    1   0.000   0.000   0.000
    2  -5.259   1.456 -24.857
    3   0.004   0.004   0.004

ADJUSTED VECTORS, GROUP 1:
                               DX,DY,DZ    V       DN,DE,DU    v       v'

ETLE   ETLN     253 A          98.413 -0.005      -31.751  0.001    0.2
                                9.931  0.002       98.146 -0.005   -0.8
                              -30.838 -0.001       -9.690 -0.004   -0.3

ETLN   HEC2     253 A        -110.089  0.005      300.855 -0.004   -0.6
                              159.252  0.001      -71.758  0.005    0.8
                              241.444 -0.004       10.632 -0.002   -0.2

ETLE   HEC2     253 B         -11.676 -0.000      269.103  0.002    0.3
                              169.183 -0.001       26.388 -0.001   -0.1
                              210.605  0.003        0.942  0.003    0.2

ETLE   ETLN     253 B          98.413  0.008      -31.751 -0.005   -0.7
                                9.931 -0.001       98.146  0.007    1.0
                              -30.838 -0.004       -9.690 -0.001   -0.1

ETLE   HEC2     253 B         -11.676 -0.000      269.103  0.002    0.3
                              169.183 -0.001       26.388 -0.001   -0.1
                              210.605  0.003        0.942  0.003    0.2

ETLN   HEC2     253 B        -110.089 -0.006      300.855  0.001    0.2
                              159.252  0.002      -71.758 -0.006   -0.8
                              241.444 -0.000       10.632 -0.003   -0.2

S.E. OF UNIT WEIGHT =      0.593
```

Figure F-5. Free adjustment of network (Continued)

```
NUMBER OF -
   OBS. EQUATIONS              22
   UNKNOWNS                    10
   DEGREES OF FREEDOM          12
   ITERATIONS                   0


GROUP  1 ROT. ANGLES (sec.) AND SCALE DIFF. (ppm):

HOR. SYSTEM          0.000   0.000   0.000   0.000
STD. ERRORS          0.001   0.001   0.001   0.001
XYZ SYSTEM           0.000   0.000   0.000

ADJUSTED POSITIONS:

                   LAT.              LON.          ELEV.    STD. ERRORS (m)

   1  ETLE    38 44 27.46754   77  8 40.41060    -7.020 0.000 0.000 0.000
   2  ETLN    38 44 26.43961   77  8 36.34626   -16.791 0.002 0.002 0.005
   3  HEC2    38 44 36.19477   77  8 39.32328    -5.896 0.002 0.002 0.005

ACCURACIES (m):
                                  D. LAT.    D. LON.     VERT.

ETLE           ETLN              0.002       0.002       0.005
ETLN           HEC2              0.002       0.002       0.005
ETLE           HEC2              0.002       0.002       0.005
ETLE           ETLN              0.002       0.002       0.005
ETLE           HEC2              0.002       0.002       0.005
ETLN           HEC2              0.002       0.002       0.005


*****************************************************************
****                                                         ****
****              ESTIMATES OF PRECISION                     ****
****                                                         ****
****     Based on the VECTOR ACCURACIES produced by          ****
****                     FILLNET                             ****
****                                                         ****
****   This is a reasonable estimate of the accuracies       ****
****     of the vectors in the network at 1 SIGMA.           ****
****                                                         ****
*****************************************************************

   VECTOR          LENGTH     PPM(h)  RATIO(h)     PPM(v)  RATIO(v)

ETLE   ETLN        103.608    27.4  1:    36470    48.3  1:    20722
ETLN   HEC2        309.477     9.1  1:   109352    16.2  1:    61895
ETLE   HEC2        270.395    10.5  1:    95599    18.5  1:    54079
ETLE   ETLN        103.608    27.4  1:    36470    48.3  1:    20722
ETLE   HEC2        270.395    10.5  1:    95599    18.5  1:    54079
ETLN   HEC2        309.477     9.1  1:   109352    16.2  1:    61895
```

Figure F-5. (Concluded)

Appendix G
Guide Specification for NAVSTAR Global Positioning System (GPS) Surveying Services

INSTRUCTIONS

G-1. General

This guide specification is intended for use in preparing Architect-Engineer (A-E) contracts for professional surveying and mapping services where use of GPS methods is an integral part of the effort. These specifications are applicable to all A-E contracts used to support U.S. Army Corps of Engineers (USACE) civil works and military construction design, construction, operations, maintenance, regulatory, and real estate activities. Since GPS is only a tool for supporting topographic, photogrammetric, or hydrographic surveys, an exclusive GPS survey contract would not normally be developed -- these specifications would be incorporated in a traditional site plan mapping, photogrammetric mapping, or hydrographic surveying contract. This guide specification is intended for contracts which are obtained using PL 92-582 (Brooks Act) qualification-based selection procedures.

G-2. Coverage

This guide specification contains the technical standards and/or references necessary to specify the more common static and kinematic differential (carrier phase tracking) GPS surveying methods which are currently (1994) in use. It is intended to support precise GPS control surveys performed for engineering and construction purposes. This guide supports the following types of differential GPS carrier phase surveying:

- Static Differential GPS Positioning.
- Rapid Static Differential GPS Positioning.
- Stop-and-Go Differential GPS Positioning.
- Kinematic GPS Differential Positioning.
- Pseudo-kinematic Differential GPS Positioning.
- Real-time On-the-Fly Differential GPS Positioning.

Continuing redevelopments of the above applications, along with the evolution of newer GPS survey techniques, mandate that these guide specifications be continuously evaluated by USACE Commands to insure they are technologically current.

G-3. Applicability

The following types of negotiated A-E contract actions are supported by these instructions:

a. Fixed-price surveying service contracts requiring GPS control.

b. Indefinite delivery type (IDT) surveying contracts.

c. A multi-discipline surveying and mapping IDT contract in which GPS surveying services is a line item supporting other surveying, mapping, hydrography, and/or photogrammetry services.

d. A work order or delivery order placed against an IDT contract.

e. Design and design-construct contracts which include incidental surveying and mapping services (including Title II services). Both fixed-price and IDT contracts are supported by these instructions.

G-4. Contract Format

The contract format outlined in this guide follows that prescribed in EFARS 15.406-1. This contract format is designed to support PL 92-582 (SF 252) qualification based A-E procurement actions.

G-5. General Guide Use

In adapting this guide specification to any project, specific requirements will be changed as necessary for the work contemplated. Changes will be made by deletions or insertions within this format. With appropriate adaptation, this guide form may be tailored for direct input in the Standard Army Automated Contracting System (SAACONS). Clauses and/or provisions shown in this guide will be renumbered during SAACONS input.

G-6. Insertion of Technical Specifications

This guide is intended to be used in coordination with Engineer Manual (EM) 1110-1-1003, NAVSTAR GPS Surveying.

a. This manual shall be attached to and made part of any service contract for GPS surveying. The manual contains complete specifications and quality control criteria for the total (field-to-finish) execution of a GPS control survey. References to this EM are made throughout this guide. These references will normally suffice for most USACE GPS survey specifications; however the guide also identifies areas where deviations from this manual must be considered.

b. Technical specifications for GPS surveying which are specific to the project (including items such as the scope of work, procedural requirements, and accuracy requirements) will be placed under Section C of the SF 252 (Block 10). The prescribed format for developing the technical specifications is contained in this guide specification. Project-specific technical specifications shall not contain contract administrative functions -- these should be placed in more appropriate sections of the contract, which are indicated in EFARS 15.406-1 or Part 14 of the Federal Acquisition Regulations (FAR).

c. Standards and other specifications referenced in this guide specification should be checked for obsolescence and for dates and applicability of amendments and revisions issued subsequent to the publication of this specification. Use Engineer Pamphlet (EP) 25-1-1, Index of USACE/OCE Publications. Maximum use should be made of existing EM's, Technical Manuals, and other recognized industry standards and specifications.

d. Throughout Section C of this guide, the specification writer must elect a contract performance method: (1) the government designs the GPS occupation/observing schedule, or (2) the contractor designs his performance method based on the criteria given in EM 1110-1-1003. Selection of the first method depends on the GPS survey expertise of the specification writer. This method also transfers much of the contract risk to the government. The second method is the preferred contract procedure.

G-7. Alternate Clauses/Provisions or Options

In order to distinguish between required clauses and optional clauses, required clauses are generally shown in capital letters. Optional or selective clauses, such as would be used in a work order, are generally in lower case. In other instances, alternate clauses/provisions may be indicated by brackets "[ ]" and/or clauses preceded by a single asterisk "*". A single asterisk signifies that a clause or provision which is inapplicable to the particular section may be omitted, or that a choice of clauses may be made depending upon the technical surveying and mapping requirement. Clauses requiring insertion of descriptive material or additional project-specific specifications are indicated by either ellipsis or underlining in brackets (e.g., "[...]" "[_____]"). In many instances, explanatory notes are included regarding the selection of alternate clauses or provisions.

G-8. Notes and Comments

General comments and instructions used in this guide are contained within asterisk blocks. These comments and instructions should be removed from the final contract.

G-9. Indefinite Delivery Type Contracts and Individual Work Order Assignments

Contract clauses which pertain to IDT contracts, or delivery orders thereto, are generally indicated by notes adjacent to the provision. These clauses should be deleted for fixed-price contracts. In general, sections dealing with IDT contracts are supplemented with appropriate comments pertaining to their use. Work orders against a basic IDT contract may be constructed using the format contained in Section C of this guide. This contract section is therefore applicable to any type of GPS service contracting action.

THE CONTRACT SCHEDULE

SECTION A

SOLICITATION/CONTRACT FORM

****

NOTE: Include here Standard Form 252.

****

SF 252 -- (Block 5): PROJECT TITLE AND LOCATION

****

NOTE: The following sample titles represent projects under which static or kinematic GPS surveys are expected to play a significant role in developing basic project control, photo control, or local site plan mapping control. GPS surveys are used to support subsequent photogrammetric, plane table/total station site plan mapping, and construction layout operations.

****

{Fixed-price contract -- sample title}:

PROJECT CONTROL AND PHOTOGRAMMETRIC MAPPING CONTROL SURVEYS USING KINEMATIC DIFFERENTIAL NAVSTAR GPS IN SUPPORT OF SITE PLAN MAPPING FOR PRELIMINARY CONCEPT DESIGN OF FAMILY HOUSING COMPLEX ALPHA, FORT ______________, ALABAMA.

PROJECT CONTROL REFERENCE SURVEYS USING KINEMATIC DIFFERENTIAL NAVSTAR GPS POSITIONING FOR BOUNDARY DEMARCATION SURVEYS OF ______________ [PROJECT], ______________, CALIFORNIA.

{Indefinite Delivery Type contract -- sample title}:

INDEFINITE DELIVERY CONTRACT FOR GEODETIC CONTROL, TOPOGRAPHIC MAPPING, AND RELATED SURVEYING SERVICES IN SUPPORT OF VARIOUS *[CIVIL WORKS] [MILITARY CONSTRUCTION] PROJECTS *[IN] [ASSIGNED TO] THE ________________ DISTRICT.

SECTION B

SERVICES AND PRICES/COSTS

****

NOTE: The fee schedule for photogrammetric mapping and related survey services should be developed in conjunction with the preparation of the independent government estimate (IGE) along with the technical specifications. The unit of measure (U/M) used in a fee schedule for GPS mapping services is generally established on a daily rate basis (i.e., crew-day). U/Ms based on "per occupied point" or "per baseline observation" are no longer recommended given the high variability in GPS equipment production.

The table below contains sample fee schedules which may be tailored for use on most GPS control surveying or mapping service contracts. The guide writer should select those line items applicable to the project, or for those projects envisioned over the course of an IDT contract. Other line items may be added which are unique to the project(s). If applicable, a separate fee schedule for

contract option periods should be developed and negotiated during contract negotiations and included with the contract during initial award. Unit prices shall include direct and indirect overheads. Profit is not included on IDT contract unit prices.

Procedures for estimating line item unit prices (U/P) are described in EM 1110-1-1000. Determination of these estimated unit prices should conform to the detailed analysis method, or "seven-item breakdown." The scope of each scheduled line item used in Section B must be thoroughly defined -- either with the line item in Section B or at its corresponding reference in Section C of the contract. Many of the line item units of measure are comprised of costs from a variety of sources. These sources are combined in the IGE to arrive at the scheduled rate. Survey crew day rates normally include labor, travel, transportation, expendable materials, and numerous other items which are developed as part of the IGE. However, large items, such as travel, may be separately scheduled.

On IDT contracts, the specification writer should strive to avoid scheduling items which have little probability of being required during the contract period. Since each line item must be separately estimated and negotiated, considerable government (and contractor) resources may be consumed in developing negotiated unit costs for unused items. Individual line items should not be included on an IDT contract unless there is a fair degree of assurance that these items will be required on a subsequent work order.

In addition, the specification writer should attempt to include only those line items that represent a major cost activity/phase in performing GPS surveying and mapping. Cost estimating emphasis and resources should be placed on major cost items, such as field crew labor. Avoid cluttering the schedule with small and relatively insignificant (to the overall project cost) supply and material items; again, minimizing the administrative costs of estimating and negotiating these items. These should be included as part of a major line item or be contained in the firm's overhead. Examples of normal supply items which the guide user should avoid scheduling are field survey books or bundles of 2" x 2" survey stakes. These items would, however, be compensated for in the IGE. Care must be taken (in developing these schedules with the IGE) to preclude against duplication of costs between line items or overheads. Specific personnel and equipment requirements should be identified and itemized in applicable contract sections. This is particularly important when breaking out GPS receiver costs. The guide user (and cost estimator) must have a good working knowledge of GPS field mapping and data reduction processes to properly allocate time and costs.

The following schedules may be tailored for either A-E fixed-price or A-E IDT contracts. For fixed-price contracts, the estimated quantities are available from the government estimate. For IDT contracts, a unit quantity for each line item would be negotiated and included in the basic contract. Daily units of measure (U/M) may be modified to hourly or other nominal units if needed. Lump sum or areal U/M (e.g., per baseline observation) may be developed for some of the services, although this is not recommended. The item numbers shown are for reference in this guide only -- they would be renumbered in the final contract.
****

ITEM	DESCRIPTION	QUAN	U/M	U/P	AMOUNT
0001	Registered/Licensed Land Surveyor-Office	[1]	Day		
0002	Registered/Licensed Land Surveyor-Field	[1]	Day		
0003	Civil Engineering Technician -- Field Party Supervisor (Multiple Crews)	[1]	Day		
0004	Engineering Technician (Draftsman)-Office	[1]	Day		
0005	Supervisory Survey Technician (Field)	[1]	Day		
0006	Surveying Technician -- GPS Instrumentman/Recorder	[1]	Day		
0007	Surveying Aid -- Rodman/Chainman {Conventional surveys}	[1]	Day		
0008	[Two][Three][Four][___]- Man [Static] [Kinematic] GPS Survey Party [___] GPS Receiver(s) [___] Vehicle(s) [___] Computer(s) {Detail specific personnel/equipment requirements in applicable contract sections - see PARC IL 92-4}	[1]	Crew Day		
0009	Additional GPS Receiver {Add Item 0006 observers as necessary}	[1]	Day		
0010	{Travel/Per Diem -- add line item if not included in above items}	[1]	Day		
0011	Survey Technical (Office Computer)	[1]	Day		
0012					
0013					

SECTION C

STATEMENT OF WORK

C.1 GENERAL. THE CONTRACTOR, OPERATING AS AN INDEPENDENT CONTRACTOR AND NOT AN AGENT OF THE GOVERNMENT, SHALL PROVIDE ALL LABOR, MATERIAL, AND EQUIPMENT NECESSARY TO PERFORM THE PROFESSIONAL SURVEYING *[AND MAPPING WORK] *[FROM TIME TO TIME] DURING THE PERIOD OF SERVICE AS STATED IN SECTION D, IN CONNECTION WITH PERFORMANCE OF *[____________] SURVEYS *[AND THE PREPARATION OF SUCH MAPS] AS MAY BE REQUIRED FOR *[ADVANCE PLANNING,] [DESIGN,] [AND CONSTRUCTION] [or other function] [ON VARIOUS PROJECTS] *[specify project(s)] . THE CONTRACTOR SHALL FURNISH THE REQUIRED PERSONNEL, EQUIPMENT, INSTRUMENTS, AND TRANSPORTATION, AS NECESSARY TO ACCOMPLISH THE REQUIRED SERVICES AND FURNISH TO THE GOVERNMENT REPORTS AND OTHER DATA TOGETHER WITH SUPPORTING MATERIAL DEVELOPED DURING THE FIELD DATA ACQUISITION PROCESS. DURING THE PROSECUTION OF THE WORK, THE CONTRACTOR SHALL PROVIDE ADEQUATE PROFESSIONAL SUPERVISION AND QUALITY CONTROL TO ASSURE THE ACCURACY, QUALITY, COMPLETENESS, AND PROGRESS OF THE WORK.

****

NOTE: The above clause is intended for use on an IDT contract for survey services. It is not exclusive to GPS-performed surveys. It may be used for Fixed-price service contract by deleting appropriate IDT language and adding the specific project survey required. This clause is not repeated on individual delivery orders.

****

C.2 LOCATION OF WORK.

****

NOTE: Use the following clause for a fixed-scope contract or individual work order.

****

C.2.1. *[STATIC] [KINEMATIC] SURVEYS USING NAVSTAR GPS EQUIPMENT SHALL BE PERFORMED AT [...] *[list project area or areas required]. *[A MAP DETAILING THE WORK SITE IS ATTACHED AT SECTION G OF THIS CONTRACT.]

****

NOTE: Use the following when specifying an indefinite delivery contract for surveying and mapping services.

****

C.2.2. SURVEYING SERVICES SHALL BE PERFORMED IN CONNECTION WITH PROJECTS *[LOCATED IN] [ASSIGNED TO] THE [____________] DISTRICT. *[THE ______________ DISTRICT INCLUDES THE GEOGRAPHICAL REGIONS WITHIN *[AND COASTAL WATERS] [AND RIVER SYSTEMS] ADJACENT TO:]

*______________________________

{list states, regions, etc.}

****

NOTE: Note also any local points-of-contact, right-of-entry requirements, clearing restrictions, installation security requirements, etc.

****

C.3 TECHNICAL CRITERIA AND STANDARDS.

REFERENCE STANDARDS:

C.3.1. U.S. ARMY CORPS OF ENGINEERS EM 1110-1-1003, NAVSTAR GPS SURVEYING. THIS REFERENCE IS ATTACHED TO AND MADE PART OF THIS CONTRACT. (SEE CONTRACT SECTION G).

C.3.2. U.S. ARMY CORPS OF ENGINEERS EM 1110-1-1002, SURVEY MARKERS AND MONUMENTATION. *[THIS REFERENCE IS ATTACHED TO AND MADE PART OF THIS CONTRACT. (SEE CONTRACT SECTION G).]

C.3.3. *[List other applicable USACE reference manuals and standards].

****

NOTE: Reference may also be made to other applicable Engineer Manuals or standard criteria documents. Such documents need not be attached to the Contract; if attached, however, reference should be made to their placement in contract Section G.

****

C.4 WORK TO BE PERFORMED. PROFESSIONAL NAVSTAR GPS SURVEYING AND MAPPING SERVICES TO BE PERFORMED UNDER THIS CONTRACT ARE LISTED BELOW. UNLESS OTHERWISE INDICATED IN THIS CONTRACT *[OR IN DELIVERY ORDERS THERETO], EACH REQUIRED SERVICE SHALL INCLUDE FIELD-TO-FINISH EFFORT.

****

NOTE: The following clauses under this paragraph may be used for either Fixed-price service contracts, IDT work orders under an IDT contract, or IDT contracts where GPS control services are part of a schedule of various survey disciplines. Clearly identify the functional requirements of any GPS surveys, including recommended static or kinematic procedures.

Fixed-scope contracts: Detail specific GPS surveying and mapping technical work requirements and performance criteria which are necessary to accomplish the work.

IDT contracts and work orders: Since specific project scopes are indefinite at the time a basic contract is prepared, only general technical criteria and standards can be outlined. Project or site-specific criteria will be contained in each delivery order, along with any deviations from technical standards identified in the basic IDT contract. The clauses contained herein are used to develop the general requirements for a basic IDT contract. Subsequent delivery orders will reference these clauses; adding project-specific work requirements as required. Delivery order formats should follow the outline established for the basic IDT contract.

****

C.4.1. GENERAL REQUIREMENTS (GPS SURVEYS). BASIC PROJECT CONTROL SURVEYS SHALL BE PERFORMED USING PRECISE DIFFERENTIAL CARRIER-PHASE TRACKING NAVSTAR GPS MEASUREMENT PROCEDURES. DIFFERENTIAL GPS BASELINE VECTOR OBSERVATIONS SHALL BE MADE IN STRICT ACCORDANCE WITH THE CRITERIA CONTAINED IN EM 1110-1-1003, EXCEPT AS MODIFIED OR AMPLIFIED HEREIN. THE GPS MEASUREMENT TECHNIQUE TO BE EMPLOYED IN MEASURING RELATIVE BASELINE VECTORS FOR *[PROJECT CONTROL] [PHOTO CONTROL] [TOPOGRAPHIC SITE PLAN MAPPING] IS *[STATIC] [STOP-AND-GO] [RAPID STATIC] [KINEMATIC] [RTK] [OTF] [PSEUDO-KINEMATIC], *[OR COMBINATIONS THEREOF]. *[CONVENTIONAL SURVEY METHODS SHALL BE USED TO DENSIFY SUPPLEMENTAL POINTS RELATIVE TO ESTABLISHED GPS STATIONS.] *[SPECIFIC GPS BASELINES TO BE OCCUPIED AND OBSERVED IN THE DIFFERENTIAL MODE ARE INDICATED IN THESE SPECIFICATIONS.]

C.4.2. HORIZONTAL ACCURACY REQUIREMENTS. NEW *[PRIMARY] STATIONS SHALL BE ESTABLISHED TO A *[__________]-ORDER, *[CLASS *[___]] RELATIVE ACCURACY CLASSIFICATION, OR *[___ PART IN ______]. *[SUPPLEMENTAL TOPOGRAPHIC/PHOTOGRAMMETRIC MAPPING POINTS SHALL BE ESTABLISHED TO A *[__________]-ORDER, *[CLASS *[___]] RELATIVE ACCURACY CLASSIFICATION, OR *[___ PART IN ______].] *[GPS HORIZONTAL ACCURACY REQUIREMENTS SPECIFIED FOR NEWLY POSITIONED STATIONS SHALL BE BASED ON A FREE (UNCONSTRAINED) ADJUSTMENT OF OBSERVATIONS AND SHALL MEET THE RELATIVE ACCURACY AND/OR LOOP MISCLOSURE CRITERIA INDICATED IN EM 1110-1-1003.]

****

NOTE: Note that accuracy classifications, and related contract quality control and acceptance, are based on a free adjustment of the work -- not a constrained adjustment to fixed/existing control which often is of less accuracy than the new GPS work. Horizontal accuracy classifications exceeding Second-Order, Class I (i.e., 1:50,000) will not normally be specified for USACE control work. GPS derived topographic mapping control need only meet general positional mapping requirements based on the site plan scale -- refer to ASPRS horizontal and vertical accuracy standards.

****

C.4.3. * VERTICAL ACCURACY REQUIREMENTS. GPS-DERIVED ELEVATIONS SHALL HAVE STANDARD ERRORS NOT EXCEEDING *[____] OR SHALL BE COMMENSURATE WITH THE CONTOUR INTERVAL OF THE FINAL TOPOGRAPHIC MAP BEING PRODUCED.

****

NOTE: When GPS techniques are used to establish vertical elevations for photo or topo mapping projects, the required vertical accuracy must be specified. Extreme caution must be employed in specifying the use of GPS in densifying vertical control -- its application for engineering and construction work is limited.

****

C.4.4. PROCEDURAL OBSERVATION REQUIREMENTS. NETWORK DESIGN, STATION AND BASELINE OCCUPATION REQUIREMENTS FOR STATIC AND KINEMATIC SURVEYS, SATELLITE OBSERVING TIME PER BASELINE, BASELINE REDUNDANCIES, AND CONNECTION REQUIREMENTS TO EXISTING NETWORKS, SHALL FOLLOW THE CRITERIA GIVEN IN EM 1110-1-1003, EXCEPT AS MODIFIED IN THESE SPECIFICATIONS.

****

NOTE: At this point, indicate any exceptions, modifications, and/or deviations from EM 1110-1-1003. The specification writer may optionally elect to have the contractor design his observing procedures in accordance with general EM 1110-1-1003 criteria. Alternatively, specific baselines or stations requiring occupation may be specified. Use of either option depends on the GPS and geodetic survey experience/expertise of the specification writer. The preferred method is to allow the maximum flexibility be given to the contractor to determine the most optimum network design (interconnections, traverses, loops, spurs, etc.). In specifying baselines/points that have been monumented, contingencies should be allowed for resetting marks and/or eccentric observations due to obscured satellite visibility. Maximum use of more efficient kinematic control densification methods (as opposed to static methods) should be specified.

****

C.4.5. * SPECIFIC BASELINES TO BE MEASURED.

****

NOTE: Use the above clause only if the government specification writer is designing the network.

****

*(1) THE FOLLOWING BASELINES SHALL BE OBSERVED ON THIS PROJECT: [...] *[list specific station-station baselines and any requirements for redundant observations]

*(2) THESE BASELINES ARE INDICATED BY [...] *[specify line symbol] ON THE ATTACHED MAP IN SECTION G.

C.4.6. NEW STATIONS TO BE *[MONUMENTED AND] OCCUPIED.

(1) THE FOLLOWING *[...] *[indicate number of] STATIONS ARE TO BE OCCUPIED AND POSITIONED USING GPS SURVEY TECHNIQUES: *[list/tabulate new stations name and/or area designation, accuracy requirements (order/class), redundant occupations, etc.]

(2) THE NEW STATIONS *[GENERAL LOCATIONS] ARE INDICATED WITH A *[...] *[indicate map symbol used] ON THE ATTACHED MAP. *[ACTUAL STATION LOCATION WITHIN THE GENERALLY DEFINED AREA SHALL BE SELECTED BY THE CONTRACTOR AND SHALL BE LOCATED SUCH THAT ADEQUATE SATELLITE VISIBILITY IS AFFORDED.]

C.4.7. EXISTING NETWORK CONTROL STATIONS TO BE OCCUPIED AND CONNECTED.

(1) A TOTAL OF *[...] *[specify number of] EXISTING HORIZONTAL CONTROL STATIONS SHALL BE USED TO REFERENCE HORIZONTAL GPS OBSERVATIONS ON THIS SURVEY. A LISTING OF THESE FIXED POINTS *[IS SHOWN BELOW] [IS SHOWN IN ATTACHMENT G.*]. FIXED COORDINATES ARE *[NAD 27] [NAD 83] [WGS 84 GEOCENTRIC] [...].

****

NOTE: List each existing control station(s) or, alternately, refer to a map or tabulation attachment in contract Section G.

****

(2) A TOTAL OF *[...] [specify number] VERTICAL CONTROL STATIONS (BENCHMARKS) SHALL BE OCCUPIED AND USED TO CONTROL AND/OR PROVIDE VERTICAL ORIENTATION REFERENCE TO GPS VERTICAL COMPONENTS. A LISTING OF THESE FIXED BENCHMARKS *[IS SHOWN BELOW] [IS SHOWN IN ATTACHMENT G.*]. ELEVATIONS FOR ALL FIXED BENCHMARKS ARE BASED ON *[NGVD 29] [NAVD 88] [IGLD-55] [...] DATUM. GEOID SEPARATION IS *[...] [ASSUMED TO BE ZERO].

****

NOTE: List or reference attachment for existing benchmarks.

****

(3) REQUIRED GPS BASELINE CONNECTIONS TO EXISTING CONTROL IS SHOWN ON ATTACHMENT G.* IN SECTION G. THESE FIXED POINTS SHALL BE USED IN PERFORMING A FINAL CONSTRAINED ADJUSTMENT OF ALL NEW WORK. HORIZONTAL POINTS ARE INDICATED BY A [...], VERTICAL POINTS BY A [...], COMBINED POINTS BY A [...], AND GPS BASELINES BY A [...].

****

NOTE: Use the above clause when existing control points to be connected are specified in the contract.

****

(4) ALL HORIZONTAL AND VERTICAL MONUMENTS ARE KNOWN TO BE IN-PLACE AS OF *[date]. DESCRIPTIONS FOR EACH POINT *[WILL BE PROVIDED PRIOR TO CONTRACT AWARD] *[ARE ATTACHED AT CONTRACT SECTION G]. THE SOURCE AGENCY, AND ESTIMATED ACCURACY, OF EACH POINT IS INDICATED ON THE DESCRIPTION. *[A GPS OBSTRUCTION SKETCH IS SHOWN ON (HAS BEEN ADDED

TO) THE DESCRIPTIONS.] *[IF SATELLITE VISIBILITY IS OBSCURED AT AN EXISTING STATION, THEN A NEW MARK SHALL BE SET AT THE RATE FOR ITEM [____] IN SECTION B.] *[THE CONTRACTOR'S FIELD REPRESENTATIVE SHALL IMMEDIATELY NOTIFY THE GOVERNMENT'S CONTRACTING OFFICER REPRESENTATIVE IF EXISTING CONTROL POINTS HAVE BEEN DISTURBED AND/OR SATELLITE VISIBILITIES ARE NOT AS INDICATED IN THE FURNISHED DESCRIPTIONS.]

****

NOTE: Use the following clause(s) only when network design and observation schedule/sequence will be determined by the contractor.

****

(5) * UNLESS OTHERWISE SPECIFIED IN THESE INSTRUCTIONS, AT LEAST *[ONE] [TWO] [THREE] [____] EXISTING (PUBLISHED) CONTROL STATIONS MUST BE OCCUPIED IN THE NETWORK. CONNECTION METHODS AND REDUNDANCY ARE AT THE CONTRACTOR'S OPTION. PRIOR TO USING ANY CONTROL POINTS, THE MONUMENTS SHALL BE CHECKED TO ENSURE THAT THEY HAVE NOT BEEN MOVED OR DISTURBED.

C.4.8. NEW STATION MONUMENTATION, MARKING, AND OTHER CONTROL REQUIREMENTS.

(1) ALL STATIONS SHALL BE MONUMENTED IN ACCORDANCE WITH EM 1110-1-1002, SURVEY MARKERS AND MONUMENTATION. MONUMENTATION FOR THIS PROJECT SHALL BE TYPE *[...] FOR HORIZONTAL AND TYPE *[...] FOR VERTICAL; PER EM 1110-1-1002 CRITERIA. *[MONUMENTATION SHALL BE DEFINED TO INCLUDE THE REQUIRED REFERENCE MARKS AND AZIMUTH MARKS REQUIRED BY EM 1110-1-1002.]. *[ALL MONUMENTS FOR NEW STATIONS ARE CURRENTLY IN PLACE AND DESCRIPTIONS ARE ATTACHED AT SECTION G.] *[IF SATELLITE VISIBILITY SHOWN ON THE DESCRIPTIONS IS OBSCURED AT AN EXISTING STATION, THEN A NEW MARK SHALL BE SET AT THE RATE FOR ITEM *[____] IN SECTION B.]

****

NOTE: Deviations from EM 1110-1-1002 should be indicated as required. USACE project control rarely requires supplemental reference/azimuth marks -- the optional specification clauses below should be tailored accordingly.

****

*(2) At each station, angle and distance measurements shall be made between a network station and reference marks and azimuth marks set which were established in accordance with the requirements set forth in EM 1110-1-1002. All observations shall be recorded in a standard field book.

*(a) For reference marks, two (2) directional positions are required (reject limit $\pm$10 " arc) and with steel taping performed to the nearest $\pm$0.01 foot.

*(b) Four directional positions are required to azimuth marks. The reject limit for a one-second theodolite is $\pm$5 seconds. Azimuth mark landmarks shall be easily defined/described natural features or structures which are of sufficient distance to maintain a *[$\pm$ ___]-second angular accuracy. *[______-order astronomic azimuths shall be observed to azimuth marks.]

*(c) A compass reading shall be taken at each station to reference monuments and azimuth marks.

C.4.9. STATION DESCRIPTION AND RECOVERY REQUIREMENTS.

(1) STATION DESCRIPTIONS AND/OR RECOVERY NOTES SHALL BE WRITTEN IN ACCORDANCE WITH THE INSTRUCTIONS CONTAINED IN EM 1110-1-1002. [FORM *[______] SHALL BE USED FOR THESE DESCRIPTIONS.] DESCRIPTIONS SHALL BE *[WRITTEN] [TYPED].

(2) DESCRIPTIONS *[ARE] [ARE NOT] REQUIRED FOR *[EXISTING] [AND/OR NEWLY ESTABLISHED] STATIONS.

(3) RECOVERY NOTES *[ARE] [ARE NOT] REQUIRED FOR EXISTING STATIONS.

C.4.10. MINIMUM OCCUPATION TIMES FOR OCCUPIED BASELINES. BASELINES SHALL BE OCCUPIED FOR A PERIOD OF TIME WHICH IS CONSISTENT WITH THE SPECIFIED ACCURACY REQUIREMENT FOR THE PROJECT AND/OR PARTICULAR NEW STATION/LINE. RECOMMENDED MINIMUM OCCUPATION TIMES ARE CONTAINED IN EM 1110-1-1003. UNLESS OTHERWISE STATED IN THESE SPECIFICATIONS, THE CRITERIA SHOWN IN THIS MANUAL SHALL BE FOLLOWED FOR EACH PROJECT AND/OR OBSERVED BASELINE. MINIMUM OCCUPATION TIMES FOR KINEMATIC GPS SURVEY OBSERVATIONS SHALL BE CONSISTENT WITH MANUFACTURER RECOMMENDATIONS AND REQUIRED ACCURACIES OF TOPOGRAPHIC FEATURES.

C.4.11. TYPE AND NUMBER OF GPS RECEIVER UNITS TO BE DEPLOYED.

(1) THE CONTRACTING OFFICER RESERVES THE RIGHT TO REQUEST PUBLISHED DOCUMENTATION ON THE ACCURACY/QUALITY OF THE HARDWARE/SOFTWARE USED FOR THIS PROJECT. ALL GPS RECEIVERS AND POST-PROCESSING SOFTWARE USED UNDER THIS *[CONTRACT] [ASSIGNMENT] SHALL BE SUBJECT TO REVIEW BY THE CONTRACTING OFFICER. SYSTEM COMPONENTS SUBJECT TO REVIEW SHALL INCLUDE:

(A) RECEIVERS
(B) ANTENNAS
(C) POWER SOURCE
(D) DATA RECORDING UNITS AND STORAGE MEDIA
(E) REAL-TIME OR POST-PROCESSING HARDWARE AND SOFTWARE

(2) A MINIMUM OF [...] GPS FIELD RECEIVER UNITS SHALL BE CONTINUOUSLY AND SIMULTANEOUSLY DEPLOYED DURING THIS *[ASSIGNMENT] [PROJECT].

****

NOTE: Add any applicable variations due to project specific requirements.

****

C.4.12. FIELD GPS OBSERVATION RECORDING PROCEDURES.

(1) FIELD LOG *[SHEETS] [FORM] [NOTES] SHALL BE COMPLETED FOR EACH STATION OF EACH SESSION AND SUBMITTED TO THE GOVERNMENT. MINIMUM DATA FOR STATIC AND KINEMATIC OBSERVATIONS TO BE INCLUDED ON THESE FIELD LOG RECORDS ARE DESCRIBED IN EM 1110-1-1003.

(2) RAW SATELLITE TRACKING DATA, BASELINE REDUCTION DATA, AND ADJUSTMENT SOLUTIONS SHALL BE RECORDED AND SUBMITTED TO THE GOVERNMENT ON *[___-INCH FLOPPY DISKS] [A PRE-APPROVED MEDIUM].

(3) IT SHALL BE THE RESPONSIBILITY OF THE CONTRACTOR TO ASSURE THAT AMPLE OBSERVATIONS ARE CONDUCTED SO THAT ALL POINTS ARE INTERCONNECTED IN A COMPLETE INTERCONNECTING NETWORK OR GPS TRAVERSE SURVEY; AND/OR IN ACCORDANCE WITH THE REQUIRED BASELINE MEASUREMENTS SPECIFIED HEREIN. *[ADEQUATE FIELD COMPUTATIONAL CAPABILITY SHALL EXIST IN ORDER TO VERIFY MISCLOSURES PRIOR TO SITE DEPARTURE.]

C.4.13. BASELINE DATA REDUCTION REQUIREMENTS (CONTROL SURVEYS).

(1) SOFTWARE FOR POST-PROCESSING OF SATELLITE TRACKING DATA SHALL BE SUBJECT TO APPROVAL BY THE CONTRACTING OFFICER. ALL SOFTWARE MUST BE ABLE TO PRODUCE FROM THE RAW DATA RELATIVE POSITION COORDINATES *[AND CORRESPONDING VARIANCE-COVARIANCE STATISTICS WHICH IN TURN CAN BE USED AS INPUT TO THREE-DIMENSIONAL NETWORK ADJUSTMENT PROGRAMS.]

****

NOTE: Baseline output statistics are generally only specified when rigorous least-squares adjustments are required; and then only if the specified adjustment software utilizes such statistics. This is not applicable to topographic surveying uses of GPS.

****

(2) BASELINE PROCESSING SHALL BE COMPLETED FOR ALL BASELINES AND SELECTED FOR USE IN THE FINAL NETWORK ADJUSTMENT BASED ON AN ANALYSIS OF THE STATISTICAL DATA AND RELATIVE SPATIAL RELATIONSHIPS BETWEEN POINTS. TEST CONSTANTS GIVEN FOR A PARTICULAR SOFTWARE SYSTEM SHALL BE COMPARED TO THE PROCESSED RESULTS AND ANY SUSPECT BASELINE THAT DOES NOT MEET THE CRITERIA SHALL BE REOBSERVED OR NOT INCLUDED IN THE FINAL ADJUSTMENT. BASELINE ACCEPTANCE AND REJECTION CRITERIA ARE CONTAINED IN EM 1110-1-1003.

C.4.14. FINAL ADJUSTMENT REQUIREMENTS (CONTROL SURVEYS). GPS SURVEY TRAVERSE LOOPS AND NETWORKS SHALL BE ADJUSTED AND EVALUATED IN ACCORDANCE WITH THE PROCEDURES AND CRITERIA OUTLINED IN EM 1110-1-1003. FINAL VECTOR MISCLOSURES MAY BE PROPORTIONATELY DISTRIBUTED AMONG THE OBSERVED VECTORS USING EITHER APPROXIMATE OR LEAST-SQUARES ADJUSTMENT TECHNIQUES DESCRIBED IN EM 1110-1-1003.

(1) ADJUSTMENTS ARE NORMALLY PERFORMED USING X-Y-Z GEOCENTRIC COORDINATES RELATIVE TO THE WGS 84 SPHEROID. TRANSFORMED FINAL ADJUSTED HORIZONTAL DATA SHALL BE EXPRESSED IN *[SPCS] [UTM] [GEOGRAPHIC] [GEOCENTRIC] [OTHER] COORDINATES, AND SHALL BE REFERENCED TO *[NAD 27] [NAD 83] [PROJECT] DATUM. FINAL COORDINATES SHALL BE TABULATED IN *[METERS] [FEET] [other] TO ONLY *[___] DECIMAL POINTS OF PRECISION. *[FINAL ADJUSTED VERTICAL DATA FOR TOPOGRAPHIC MAPPING APPLICATIONS SHALL BE SHOWN AS ORTHOMETRIC HEIGHTS ON *[NGVD 29] [NAVD 88] [other] VERTICAL DATUM. GPS-DERIVED ELEVATIONS SHALL BE ROUNDED TO THE NEAREST *[METER] [FOOT].]

* (2) FOR PROJECT CONTROL SURVEYS AN ADJUSTMENT ANALYSIS SHALL INCLUDE THE FOLLOWING:

* (a) GPS TRAVERSE LOOPS SHALL BE ANALYZED RELATIVE TO THE INTERNAL CLOSURE CRITERIA GIVEN IN EM 1110-1-1003. INTERNAL ACCEPTABILITY OF THE WORK WILL BE BASED ON THE MAGNITUDE OF THE THREE-DIMENSIONAL VECTOR MISCLOSURES RELATIVE TO THE LOOP LENGTH. SUCH LOOP CLOSURE ANALYSIS WILL BE CONSIDERED THE INTERNAL, MINIMALLY CONSTRAINED, FREE ADJUSTMENT. LOOPS/LINES WITH INTERNAL MISCLOSURE RATIOS IN EXCESS OF THOSE SPECIFIED IN THIS CONTRACT SHALL BE REOBSERVED. MISCLOSURES BETWEEN EXTERNAL FIXED CONTROL MAY BE DISTRIBUTED USING THE APPROXIMATE DISTRIBUTION METHODS GIVEN IN EM 1110-1-1003. FINAL CONSTRAINED ACCURACY ESTIMATES WILL BE BASED ON RELATIVE MISCLOSURES AT FIXED POINTS.

****

NOTE: The following clauses apply only to rigorous least-squares adjustment techniques. Note that EM 1110-1-1003 does not require that a rigorous least-squares adjustment be performed for

USACE control work. The guide specifications writer must establish the technical requirement for such an adjustment method and modify the clauses in this section accordingly.
****

(b) * WHEN A FREE (OR MINIMALLY CONSTRAINED) LEAST-SQUARES ADJUSTMENT IS PERFORMED ON THE BASELINE VECTORS, A CLASSIFICATION BASED ON THIS INTERNAL ADJUSTMENT SHALL BE DERIVED AND EVALUATED AGAINST THE MINIMUM ALLOWABLE STANDARDS SHOWN IN EM 1110-1-1003 FOR THE GIVEN REQUIRED ACCURACY. THIS FREE ADJUSTMENT, ALONG WITH AN ANALYSIS OF THE BASELINE REDUCTION DATA, WILL BE USED IN EVALUATING THE CONTRACTUAL ACCEPTABILITY OF THE OBSERVED NETWORK. STATION *[________] SHALL BE HELD FIXED FOR THIS UNCONSTRAINED ADJUSTMENT. THE NORMALIZED RESIDUALS SHALL BE COMPUTED AND ANALYZED RELATIVE TO THE CRITERIA CONTAINED IN EM 1110-1-1003. THE VARIANCE OF UNIT WEIGHT FOR THE MINIMALLY CONSTRAINED NETWORK ADJUSTMENT SHALL CONFORM TO THE CRITERIA GIVEN IN EM 1110-1-1003. RELATIVE LINE ACCURACIES SHALL BE COMPUTED FOR PAIR OF POINTS ON THE NETWORK USING STATISTICAL DATA CONTAINED IN THE FREE ADJUSTMENT. THESE RELATIVE LINE ACCURACIES SHALL NOT EXCEED THE REQUIRED ACCURACY CLASSIFICATIONS PRESCRIBED FOR THE WORK. STATIONS/BASELINES/NETWORK AREAS WITH FREE ADJUSTMENT RELATIVE ACCURACIES NOT MEETING THE REQUIRED CRITERIA MUST BE REOBSERVED; IT IS THEREFORE CONTINGENT ON THE CONTRACTOR TO ENSURE THAT MISCLOSURE TOLERANCES ARE CHECKED IN THE FIELD.

(c) * A CONSTRAINED LEAST-SQUARES ADJUSTMENT SHALL BE PERFORMED HOLDING *[FIXED] [PARTIALLY CONSTRAINED] THE COORDINATES OF THE STATIONS LISTED UNDER THE EXISTING CONTROL CLAUSE IN THIS CONTRACT SECTION. FOR THE PURPOSE OF THESE SPECIFICATIONS, BOTH FULLY CONSTRAINED AND PARTIALLY CONSTRAINED POINTS ARE REFERRED TO AS "FIXED" POINTS. THE CONSTRAINED LEAST SQUARES ADJUSTMENT SHALL USE MODELS WHICH ACCOUNT FOR: THE REFERENCE ELLIPSOID FOR THE REFERENCE CONTROL, THE ORIENTATION AND SCALE DIFFERENCES BETWEEN THE SATELLITE AND NETWORK CONTROL DATUMS, GEOID-ELLIPSOID RELATIONSHIPS, AND DISTORTIONS AND/OR RELIABILITY IN THE NETWORK CONTROL.

****

NOTE: Few USACE surveys for engineering and construction require rigorous geodetic adjustments; therefore, these clauses should be specified with caution. A variety of free and/or constrained adjustment combinations may be specified. Specific stations to be held fixed may have been indicated in a prior contract section or the contractor may be instructed to determine the optimum adjustment, including appropriate weighting for constrained points. When fixed stations are to be partially constrained, then appropriate statistical information must be provided -- either variance-covariance matrices or relative positional accuracy estimates which may be converted into approximate variance-covariance matrices in the constrained adjustment.
****

[1] *WHEN DIFFERENT COMBINATIONS OF CONSTRAINED ADJUSTMENTS ARE PERFORMED DUE TO INDICATIONS OF ONE OR MORE FIXED STATIONS CAUSING UNDUE BIASING OF THE DATA, AN ANALYSIS SHALL BE MADE AS TO A RECOMMENDED SOLUTION WHICH PROVIDES THE BEST FIT FOR THE NETWORK. ANY FIXED CONTROL POINTS WHICH SHOULD BE READJUSTED (TO ANOMALIES FROM THE ADJUSTMENT(S)) SHOULD BE CLEARLY INDICATED IN A FINAL ANALYSIS RECOMMENDATION.

[2] *THE FINAL ADJUSTED HORIZONTAL AND/OR VERTICAL COORDINATE VALUES SHALL BE ASSIGNED AN ACCURACY CLASSIFICATION BASED ON THE LEAST-SQUARES ADJUSTMENT STATISTICAL RESULTS AND IN ACCORDANCE WITH THE CRITERIA INDICATED IN EM 1110-1-1003. THIS CLASSIFICATION SHALL INCLUDE BOTH THE RESULTANT GEODETIC/CARTESIAN COORDINATES AND THE BASELINE DIFFERENTIAL RESULTS. THE FINAL ADJUSTED COORDINATES SHALL STATE THE 95%

CONFIDENCE REGION OF EACH POINT AND THE (TWO-SIGMA) RELATIVE LINE ACCURACY IN PARTS PER MILLION (PPM) BETWEEN ALL POINTS IN THE NETWORK.

(3) *FINAL ADJUSTED COORDINATE LISTINGS SHALL BE PROVIDED ON HARD COPY *[AND ON *[___] [specify] COMPUTER MEDIA].

(4) * A SCALED PLOT SHALL BE SUBMITTED WITH THE ADJUSTMENT REPORT SHOWING THE PROPER LOCATIONS AND DESIGNATIONS OF ALL STATIONS ESTABLISHED.

C.5 SUBMITTAL REQUIREMENTS:

C.5.1. SUBMITTAL SCHEDULE: THE COMPLETED SURVEY REPORT SHALL BE DELIVERED WITHIN *[___ DAYS AFTER NOTICE TO PROCEED IS ISSUED] *[By calendar date]

****

NOTE: Include a more detailed submittal schedule breakdown if applicable to project.

****

C.5.2. SUBMITTED ITEMS: SUBMITTALS SHALL CONFORM TO THOSE SPECIFIED IN EM 1110-1-1003 *[EXCEPT AS MODIFIED HEREIN].

****

NOTE: Reference should be made to EM 1110-1-1003 for typical GPS survey submittal requirements. Modify and/or add items as required.

****

C.5.3. PACKAGING AND MARKING: PACKAGING OF COMPLETED WORK SHALL BE ACCOMPLISHED SUCH THAT THE MATERIALS WILL BE PROTECTED FROM HANDLING DAMAGE. EACH PACKAGE SHALL CONTAIN A TRANSMITTAL LETTER OR SHIPPING FORM, IN DUPLICATE, LISTING THE MATERIALS BEING TRANSMITTED, BEING PROPERLY NUMBERED, DATED AND SIGNED. SHIPPING LABELS SHALL BE MARKED AS FOLLOWS:

U.S. ARMY ENGINEER DISTRICT, ______________
ATTN: ______________________________
*[include office symbol and name]
CONTRACT NO. ________________________
*[DELIVERY ORDER NO. _________________]
[STREET/PO BOX] ____________________
*[complete local mailing address]

*HAND-CARRIED SUBMISSIONS SHALL BE PACKAGED AND MARKED AS ABOVE, AND DELIVERED TO THE FOLLOWING OFFICE ADDRESS:

____
*[insert office/room number as required]

****

NOTE: In this section, also reference any automated data submittal requirements for GPS observations, if applicable.

****

C.6 PROGRESS SCHEDULES AND WRITTEN REPORTS.

C.6.1. *PRE-WORK CONFERENCE:

****

NOTE: Detail any requirements for a pre-work conference after contract award, including requirements for preparing written reports for such conferences.

****

SECTION D

CONTRACT ADMINISTRATION DATA

SECTION E

SPECIAL CONTRACT REQUIREMENTS

SECTION F

CONTRACT CLAUSES

****

NOTE: Detailed breakouts of personnel and equipment requirements to be furnished by the contractor should be listed in these sections.

****

SECTION G

LIST OF ATTACHMENTS

G.1. U.S. ARMY CORPS OF ENGINEERS EM 1110-1-1003, NAVSTAR GPS SURVEYING. THIS REFERENCE IS ATTACHED TO AND MADE PART OF THIS CONTRACT.

****

NOTE: List any other attachments called for in contract section C or in other contract sections. This includes items such as:

- Marked-up project sketches/drawings.

- Station/monument descriptions or recovery notes.

- Lists of baseline connections to existing network.

- Lists of fixed (existing) stations to be connected with and adjusted to.

****

SECTION H

PRESENTATIONS, CERTIFICATIONS AND OTHER
STATEMENTS OF OFFERERS

SECTION I

INSTRUCTIONS, CONDITIONS, AND NOTICES TO OFFERERS

Appendix H
Guide Specification for "Geodetic Quality" NAVSTAR Global Positioning System (GPS) Survey Receivers and Related Equipment/ Instrumentation

INSTRUCTIONS

H-1. General

This guide specification supersedes the USACE guide CW-01334.2, 21 June 1991, "Procurement of NAVSTAR Global Positioning System (GPS) Survey Receivers and Related Instrumentation/Equipment." This guide specification is intended for use in preparation and review of specifications for geodetic quality GPS survey instrumentation, equipment, and software. The equipment may be used in static or kinematic applications where centimeter-level applications are required. The GPS data may be post-mission processed to generate positions, or the data may be computed in real time, if the appropriate software and data link are used. This guide includes the technical requirements needed to develop formally advertised specifications.

H-2. Applicability

This guide applies to differential GPS (DGPS) survey systems that provide a three-dimensional baseline between two antennas to an accuracy of about 1 cm or better. Applications include establishing and/or extending precise engineering and construction control, creating digital elevation models, camera station positioning for aerial photogrammetry, hydrographic survey vessel positioning, and tidal/water surface measuring for civil works and military construction projects. This guide supports precise differential static, kinematic, pseudo-kinematic, stop-and-go, and on-the-fly survey modes, in both post mission processing and real time applications. This guide is not intended to support real-time GPS code tracking systems that provide meter-level accuracies for general positioning or navigation applications. (Note that the equipment designed to meet the geodetic needs are generally capable of also meeting the less stringent differential code applications but at much greater cost.) Refer to Appendix I for differential code based equipment to support general meter-level positioning and navigation applications.

H-3. Coverage

This guide follows the Uniform Contract Format for supply solicitations, as outlined in Part 14.201 of the Federal Acquisition Regulations (FAR).

a. This guide may be used for either direct bid solicitations or proposal request solicitations, depending on the complexity of the required system. Evaluation factors (Part IV, Section M) are provided for contracts involving a technical review of proposals. The use of a technical review is optional.

b. A sample "Supplies of Services and Prices" schedule is included in this guide for insertion in Part I, Section B of the contract. Technical performance requirements for a DGPS survey system are in Part I, Section C (Description/ Specifications). Other contract sections that require clauses specific to DGPS equipment are noted. Nontechnical supply contract clauses/provisions, which are incorporated in Parts I, II, III, and IV of the procurement specifications, should be developed by each respective Field Operating Activity (FOA) using appropriate FAR and supplemental guidance.

c. Continuing developments in GPS survey instrumentation and techniques mandate that these guide specifications be continuously evaluated by USACE commands to ensure they are technologically current.

H-4. References

The specification writer must be thoroughly familiar with the basic GPS operating functions (e.g., determining the optimum number and technical characteristics of GPS receivers, auxiliary support equipment and instrumentation, baseline reduction software, and network adjustment criteria) to define the technical requirement options contained in this guide. Additional guidance is found in the HQUSACE POLICY MEMORANDUM, Subject: "Acquisition and Use of Differential Global Positioning System (DGPS) Equipment for USACE Activities," dated 27 January 1994. Other topical information on DGPS is contained in EM 1110-2-1003 "Hydrographic Surveying."

H-5. DGPS System Requirements

This guide may be used to procure a complete "field-to-finish" DGPS survey system. This includes the six scheduled items in Section B: (1) GPS receivers, (2) a microcomputer system, (3) GPS baseline reduction software, (4) network adjustment software, (5) a data link for real time applications, and (6) onsite training. If desired, the system may also be configured to operate with the "On-The-Fly" software developed by USACE under the Dredging Research Program. Some vendors may also supply software providing similar capability. If GPS receivers are being added to an existing system or suite of equipment, then only item (1) above would be required in the solicitation, with other items deleted as necessary. Also note that, in

general, mixing receivers from different manufacturers may not work with all techniques and software.

H-6. Alternate Clauses/Provisions or Options

Alternate clauses/provisions throughout this guide specification are indicated by a single asterisk. This asterisk signifies that provisions that are not applicable to the particular procurement should be deleted. Clauses requiring insertion of descriptive material are indicated by an asterisk and in brackets (e.g., *[ ]). When a choice of items exists, they are normally contained in successive brackets.

H-7. Notes and Comments

General comments and instructions used in this guide are contained within asterisk blocks and highlighted in bold type.

These blocked comments and instructions should be removed from the final contract.

H-8. Submittal For Review and Approval

If specifications for NAVSTAR GPS survey systems are required to be submitted to higher authority for review and approval, they shall include printed copies of this guide specification, as revised for the particular procurement action. Guidance on review requirements for GPS systems is contained in the HQUSACE POLICY MEMORANDUM, Subject: "Acquisition and Use of Differential Global Positioning System (DGPS) Equipment for USACE Activities," dated 27 January 1994.

Part I - The Contract Schedule

Section A

Solicitation/Contract Form

****

NOTE: Include here Standard Form 33 (Solicitation, Offer and Award) or Standard Form 26 (Award/Contract), as applicable.

****

Section B

Supplies or Services and Prices/Costs

****

NOTE: The sample below represents a typical schedule for procurement of GPS instrumentation and related equipment. This schedule must be tailored based on the specific technical requirements outlined in Section C of the contract.

****

Supplies/Services and Prices

Item No.	Description	Quantity	U/M	U/P	Amt
0001	Precise GPS survey receiver system, related equipment, software, data link, and other components, in accordance with the technical specifications found in Section C.	*[___]	EA	___	___

****

add for RFP evaluation or if necessary

****

* [Evaluation will be made on the basis of the technical data under the guidelines found in Section M. Failure to show compliance with the specifications will require rejection of the bid.]

****

NOTE: The following items are included if a full "field-to-finish" differential GPS survey system is required. Alternately, selected items may be used if the solicitation is to upgrade or add to existing GPS equipment.

****

Item No.	Description	Quantity	U/M	U/P	Amt
0002	*[Micro-computer system, as specified in Section C.]	___	___	___	___
0003	* [GPS baseline reduction software, as specified in Section C.]	___	___	___	___
0004	* [Network adjustment software, as specified in Section C.]	___	___	___	___
0005	* [Data link for real-time applications, as specified in Section C.]	___	___	___	___
0006	* [GPS receiver system, data reduction, processing and adjustment software training.]	___	___	___	___

****

NOTE: Add other items to the schedule as necessary. These may include tripods, tribrachs, spare batteries, data storage devices, communication/modem devices, software/hardware for navigation (e.g., survey vessel positioning and guidance control). Hardware/software interface requirements to existing survey systems (e.g., hydrographic systems) may also be separately scheduled.

****

Section C

Description / Specifications

C.1. General DGPS Description. The DGPS to be procured under this solicitation is intended for use in *[static and/or kinematic] positioning applications using the GPS carrier phase as the principle observable. The system will yield 3-dimensional vectors between a reference and "rover" station to an accuracy of *[10 mm + 2 ppm or better on baselines of 1 to 50 km when operating in a static mode] [and] *[3 cm or better on baselines up to 25 km when operating in a kinematic mode]. *[The system is intended to operate in real time with the incorporation of a communications link, as specified further in Section C of this solicitation.] *[The system will have the capability to resolve the initial integer cycle ambiguity in a robust manner, automatically, while the rover is constantly in motion, known as on-the-fly (OTF), with no more than 60 sec of data, on baselines up to 25 km in length.] *[The OTF ambiguity resolution software will operate in *[real time] *[and/or] *[post processing] applications]. *[The system procured under this solicitation will interface to, and operate with, the USACE OTF software distributed by the U.S. Army Topographic Engineering Center, ATTN: CETEC-TD-GS (OTF software), 7701 Telegraph Rd, Alexandria, Virginia 22315-3864.]

C.2. Receiver Requirements. Unless otherwise specified, the performance requirements given below shall be met by the GPS receivers in conjunction with the antenna assembly and antenna cable.

C.2.1. GPS Signal Levels. GPS receivers delivered shall acquire and track GPS signals and otherwise perform as specified herein, when the signal levels from GPS satellites incident at the antenna are within the range of minimum to maximum levels specified in ICD-PGS-200B-PR.

C.2.2. Cryptographic Keys. *[Unless otherwise specified,] GPS receivers shall perform as specified herein without requiring cryptographic keys, whether or not GPS selective availability (SA) and/or anti-spoofing (AS) are activated.

****

NOTE: Two versions of C.2.3. are given. L1 only receivers are adequate for static geodetic survey operations. Robust kinematic operations and OTF ambiguity resolution requires more capable hardware observing the full wavelength L1 and full wavelength L2 carrier phase. Choose one of the two given C.2.3 appropriately.

****

*[C.2.3. GPS Observables. The GPS receivers delivered shall provide, at a minimum, the following time-tagged observables: full L1 C/A code, L1 P-code, continuous full wavelength L1 carrier phase, L2 P-code, and continuous full wavelength L2 carrier phase.]

*[C.2.3. GPS Observables. The GPS receivers delivered shall provide, at a minimum, the following time-tagged observables: full L1 C/A code and continuous full wavelength L1 carrier phase.]

(1) Measurement Time Tags. Signal measurements (observables) shall be time tagged with the time of receipt of the signal referenced to the receiver clock. Time tags shall have a resolution of 1 μsec or better. Time tags shall be within 1 msec with respect to GPS time.

(2) Carrier Phase Accuracy. The receiver shall have L1 {*the following is required for OTF operation*} *[and l2 full wavelength] carrier-phase measurement accuracies of 0.75 cm (RMS) or better, exclusive of the receiver clock offset.

****

NOTE: The following C.2.3. (3) is for OTF operation only.

****

*[(3) Code Accuracy. The receiver shall have an L1 C/A-code phase measurement accuracy of 30 cm (RMS) or better, exclusive of receiver clock time and frequency offsets.]

C.2.4. Receiver Output. The GPS receiver shall be able to output the GPS observables as described in C.2.3. with a latency of less than 1 sec *[and, simultaneously, a differential code position and the timing information stated in 2.6]. The GPS receivers shall be able to output the information from the full GPS navigation message, as specified in ICD-GPS-200 REVB-PR. This shall include ephemeris data, almanac data, ionospheric parameters, and coordinated universal time (UTC) parameters. The UTC and ephemeris data shall be available by request or if a change has occurred in those parameters.

C.2.5. Receiver Data Rate. The GPS observable data described above shall be available at a minimum of a 1 Hz rate.

C.2.6. 1 Pulse Per Second (PPS) Output. GPS receivers delivered shall have a 1 PPS time strobe and its associated time tag. The 1 PPS pulse and time tag shall be accessible through a port (or ports) on the GPS receiver so that external system components can be time synchronized to UTC time.

C.2.7. Internal Receiver Testing. The receiver shall perform a self test and checks to detect electronic malfunctions and/or faulty data collection, including cycle slips. The receiver shall provide immediate *[audio] *[visual] notification of failures. The receiver shall perform any needed calibrations automatically.

C.2.8. Reinitialization. The receiver shall be capable of reinitializing itself and resume normal operation after a power interruption without operator assistance. The data collected by the GPS receiver shall not be lost due to power interruption but stored in the receiver or other archiving media.

C.2.9. Multiple Satellite Tracking. The receiver must be capable of tracking and observing all signals previously stated on a minimum of eight satellites simultaneously, each on an independent channel.

C.2.10. Operating Conditions. The GPS receivers delivered shall meet the following criteria:

(1) Successfully acquire and track unobstructed GPS satellites, visible 5 deg and higher above the horizon, in all weather conditions.

(2) Operate at humidity ranges of 0 to 100 percent.

(3) Operate within the temperature range of -20 °C to +50 °C.

*[(4) Be waterproof and able to operate in an ocean environment aboard open survey launches.]

*[(5) Operate in heavy rain, 50.8 mm/day (2 in./day).]

*[(6) Operate in fog.]

*[(7) Operate in and resist corrosion in salty air conditions.]

C.2.11. Receiver Power Requirements. The GPS receivers delivered shall meet the following criteria:

(1) Be self protecting from power surges, spikes, and reverse polarity.

(2) Allow the operator to switch power sources (AC, DC, or battery) while maintaining receiver operation and without loss of stored data.

(3) Provide a *[visual] *[audible] warning for low power.

(4) Be capable of operating using *[a battery pack] *[and] *[or] *[AC power] *[and] *[or] *[12-v DC] *[24-v DC] *[external DC power].

*[(5) The battery pack shall meet the following criteria:]

*[(a) Contain rechargeable battery/batteries which can operate the receiver for at least 3.5 hr on a single (re)charge.]

*[(b) Be *[either] *[internal] *[or] *[external] to the receiver.]

*[(c) Include all cables, hardware, etc. necessary to connect/install the battery pack. The batteries shall be water and dust tight and be protected from damage and inadvertent shorting of the terminals.]

*[(6) For operation using *[AC] *[and] *[external DC] *[power.]

*[(a) When operating under *[AC] *[or] *[DC] power, the unit shall be capable of simultaneously charging the battery pack. The battery pack shall power the receiver if the normal power supply is interrupted.]

*[(b) The AC power supply *[shall be internal] *[may be internal or external] to the receiver.]

*[(c) The power supply/battery charger shall provide all voltages necessary to operate the receiver and (re)charge the battery pack.]

*[(d) The power supply/battery charger shall be designed to automatically protect the battery pack from overcharging.]

*[(e) All cables and connectors needed to connect the power supply/battery charger to the power line *[and receiver] shall be included.]

*[(f) The AC power supply/battery charger shall operate from *[115-v] *[and 230-v] ac (±10 percent) *[50/] 60 Hz, single phase power.]

*[(g) The unit shall operate from external *[12-v DC] *[24-v DC] *[9 to 32-v DC] power.]

****

NOTE: Not all manufacturers provide a battery that is internal to the receiver. Moving the battery pack external to the receiver does not affect the functioning; it is a matter of design. For example, doing this could substantially decrease the size of the unit. Different manufacturers have different setups for the batteries. The District is encouraged to know what will work best for them based upon District requirements and determine the necessary battery life.

****

C.2.12. Manuals. At least two sets of complete operation and maintenance manuals shall be included with each receiver and shall cover all auxiliary components furnished with each receiver. *[Updates shall be furnished as they become available.]

C.2.13. Field Planning. The receiver shall have internal software that, as a minimum, is capable of computing the availability and positions of satellites for any given time and the current position of the GPS receiver *[and terrestrial position] using data gathered by the GPS receiver.

*[C.2.14. Dimensions. The dimensions of the receiver shall not exceed *[___] length by *[___] width by *[___] height, all such that one person can easily transport the unit.]

*[C.2.15. Weight. The receiver shall be transportable by one person. [One complete field station consisting of receiver, battery pack, antenna, and antenna cable shall not exceed * [___] kg * (__) lbs.]

*[C.2.16. Data Logger. The receiver shall be capable of recording and controlling data on an *[internal]*[external] storage device. This device shall be capable of storing a minimum of *[4] *[6] *[8] *[___] megabytes (mb) of data.]

****

NOTE: The DATA LOGGER (C.2.16.) option is required by those who wish to store data within the receiver for post mission processing. Without this capability, some external device, such as a computer and interfacing software, will be required to perform the data logging. Memory should be specified to cover the maximum expected recording durations and rates.

****

*[C.2.17. Additional Options for Meter-level DGPS Operations.]

****

NOTE: This entire section is optional. It is possible for "geodetic type" GPS receivers as described previously to perform differential code (meter-level) positioning using standard broadcast messages from systems such as the U.S. Coast Guard radio beacon network. If this type of positioning is required, then the following options should be included in the solicitation. Use of the USACE's OTF software does not depend on the following options.

****

*[(1) Format. The reference station receiver shall output dgps correction data in the radio technical commission for maritime services special committee 104 (RTCM SC-104) format, version 2.1 and U.S. Coast Guard Broadcast Standard.]

*[(2) Format. The remote station receiver shall accept and apply correction data in RTCMM SC-104 format, version 2.1.]

*[(3) Accuracy. Real time positioning accuracy relative to the reference station shall be *[2] *[6] m *[2] DRMS within a range of at least 42 km (25 miles) from the reference station.]

*[(4) Waypoints. The receivers shall have the ability to accept up to *[___] waypoints which can be selected by the helmsman.]

*[(5) Position Rate. The receiver shall be capable of providing output position fixes at rates within the range of [__] Hz to [__] Hz.]

*[(6) Velocity. The receiver shall be capable of determining *[velocity and] position while moving at speeds of up to [5.14] * [___] meters per sec (*[10] *[___] knots).]

*[C.2.18. Additional Options for Geodetic Grade Static Survey Operations.]

*[(1) Accuracy Specification. The GPS reference receiver shall be capable, when used in conjunction with a remote GPS receiver, of 10 mm + 2 ppm accuracy or better on baselines of 1 to 50 km in length when used in the static differential mode. The receivers shall have an accuracy of 10 mm or better on baselines less than 1 km.]

*[(2) Data Collection. The receiver shall not require over 1 hr of continuous data collection with a minimum of four satellites in order to achieve the accuracy requirements stated in Paragraph C.2.18 (1).]

C.2.19. GPS Antenna Assembly.

(1) Antenna Mount. The GPS antenna shall be capable of being mounted on a standard surveyor's tripod with a 5/8-in. by 11-in. threaded stud *[or to a standard wild type tribrach].

(2) Antenna Phase Center. The center instability of the 3-dimensional phase center of the GPS antenna shall be no greater than 3 mm.

(3) Receiver/Antenna Separation. The system shall allow the antenna to be located at least *[30] *[___] m from the receiver so that it can be operated remotely from the receiver with no system degradation.

(4) Antenna Cables. *[One] *[___] antenna cable(s) shall be furnished with each receiver. *[[One] *[each] of these cables should be at least *[__] m,] * [and the other cable should be at least *[__] m.] All appropriate connectors should already be attached to the cable ends. *[These cables shall be capable of being cascaded for a total length of *[___] m of cable for setup flexibility.]

(5) GPS Survey Antenna. Survey antennas shall receive GPS signals at the l1 *[and l2] frequency *[frequencies] and provide these signals to the GPS receiver. The antenna shall have an omnidirectional horizontal pattern and shall incorporate features which minimize multipath error.

*[(6) Antenna Assembly. The antenna assembly shall include the following items:

*[(a) A method to minimize ice and snow buildup.]

*[(b) A method to reduce bird nesting capability.]

*[(c) The ability to withstand strong winds up to * [___] meters per sec (*[___] knots).]

*[(d) A method to orient (to north) after mounting.]

*[(e) A mechanical mark for height measurement with known offset from phase center.]

*[(f) Operation within the temperature range of -40 °C to +65 °C.]

*[(g) Dimensions. The dimensions of the antenna shall not exceed *[45 cm] in length by *[45 cm] in width by *[15 cm] in height, all so that one person can easily transport the unit.]

*[(h) A method to reduce the effects of multipath.]

*[(i) A method to amplify the signal for cable lengths in excess of 15 m.]

*[(7) Each antenna shall be 100 percent sealed/watertight. *[One] *[___] GPS antenna shall be provided with each GPS receiver unit.]

*[(8) Antenna Pole. An antenna pole shall be provided for use during survey operations. It shall be *[a fixed height pole of 2 m] *[extendable from a length of 1 m (±0.2 m) to 2 m (with a variance of ±0.5m)] and shall allow rapid attachment and detachment of the GPS survey antenna. The pole shall include a built-in leveling device and legs which are *[collapsible and attached] *[detachable].]

*[(9) Tribrach. A standard tribrach (with adapters) shall be provided with each antenna. The tribrach shall allow the antenna to be mounted atop the tripod. The tribrach shall be able to be mounted on top of a

standard surveyor's tripod with a 5/8-in. threaded stud and shall include adapters to allow mounting of standard target sets.]

*[(10) Vehicular Antenna Mount. A survey antenna mount shall be provided that can easily be attached or detached from the vehicle. This mount shall be designed so that it remains firmly in place at speeds of up to 88.5 kmph (55 mph) on a level roadway. The mount shall be designed so that its use does not require vehicle modification.]

C.2.20. Input and Output (I/O) Ports.

(1) Standards. All I/O ports will be compatible with the RS-232 standard.

(2) I/O Ports. *[I/O ports shall be compatible with any processor, data terminal, or storage devices used in the positioning system.] *[The vendor shall provide complete documentation of the I/O ports including connector, signal descriptors, connector pin outs, communications protocols, command and message descriptions, need to set up the receiver and extract and decode the observed data.]

****

NOTE: The following options [C.2.20(3) and C.2.20(4)] are not required for the OTF system operation. They would be used for differential code position interface to marine systems such as electronic charts or hydrographic survey systems.

****

*[(3) Real time positional data out of the remote receiver will adhere to the National Maritime Electronics Association (NMEA) 0183 data sentences format and will be output over an RS-232 compatible port.]

*[(4) The receiver shall have the capability to output the data, position fixes, and calibration data through a RS-232 compatible serial port.]

C.3. Microcomputer Systems. The microcomputer shall be a portable, *[notebook style,] IBM compatible, microcomputer that is fully compatible with all software and hardware supplied under this solicitation. In addition, the following minimum features shall be included:

****

NOTE: For operation of the USACE OTF software, one microcomputer is required for each GPS receiver. A notebook style IS HIGHLY recommended.

****

C.3.1. Operate with the microsoft disk operating system (MSDOS) version 5.0 or later.

C.3.2. Utilize a *[486] *[pentium] processor.

C.3.3. Have a clock speed of at least *[33] MHz.

C.3.4. Have a minimum of *[250] megabytes of storage capacity on an internal hard drive, with a 20 msec access speed.

C.3.5. Have a minimum *[16] megabyte of random access memory.

C.3.6. Have one 3.5-in. high density disk drive.

C.3.7. Have a VGA graphics adapter.

C.3.8. Be capable of operating from the same power source as the GPS receiver.

****

NOTE: The following item, (C.3.9.), is required for the operation of the USACE OTF software and may not be required for any vendor supplied OTF or kinematic procedure.

****

*[C.3.9. Have four serial ports that are available for external use after connecting any mouse trackball, or other device included by the computer manufacturer for operating that computer.

(1) The board for the additional serial ports shall have the host addresses starting at 300 hexadecimal and the interrupts slaved to IRQ5.]

****

NOTE: Microcomputer and printer requirements must be tailored to existing USACE Command computer resources. Since this item will generally be based in the field, a dual capability may be required in the District office. Refer to EM 1110-1-1003 for additional details on GPS baseline computation and adjustment requirements.

****

C.4. GPS Baseline Processing and Reduction Software.

****

NOTE: The USACE OTF software may be used to compute 3-dimensional coordinate differences and positions of the "object" station. This software only uses the OTF ambiguity resolution technique, and is not suited for classic "static" GPS applications. This software is suited for kinematic application and will operate in real-time or post mission processing modes. A number of vendors have similar capability.

Based on FOA requirements, baseline processing software or adjustment software may not be a requirement of this solicitation.

****

C.4.1. General. The GPS baseline processing software must be fully compatible with the receivers and microprocessors listed in Paragraphs C.2. and C.3.

****

NOTE: If the microprocessor is NOT included as part of this solicitation, then the type of processor must be given to verify software compatibility.

****

C.4.2. Data Computations. The baseline reduction software shall compute, at a minimum, *[the carrier-phase integer cycle ambiguity using static and kinematic techniques, including those commonly known as "known

baseline," "rapid static," "antenna swap," "stop-and-go," and "OTF"] *[and subsequently] the 3-dimensional differential baseline components between observation stations, within the accuracy specifications given in Paragraph C.1.

C.4.3. Ephemerides. The baselines computations must utilize both the broadcast and precise ephemerides.

C.4.4. Output Data. The results of the baseline processing shall be in any user-selected form, such as *[geocentric coordinates,] *[state plane coordinates based on the North American Datum of 1927,] *[state plane coordinates based on the North American Datum of 1983,] *[and] *[or] *[universal transform mercator projection coordinates].

C.4.5. Batch Processing. The software shall have the capability to post mission process data sets unattended in a batch mode.

C.4.6. Multiple Copies. The Government shall be allowed to operate the software simultaneously on *[_____] microcomputer systems.

C.4.7. Absolute Point Positioning. The software shall be capable of processing pseudo-range data to obtain single point positions of a single receiver.

*[C.4.8. Real-Time Capability. The software shall be capable of resolving carrier cycle integer ambiguities in real time when the observing stations are connected via a communications link *[as specified elsewhere in this solicitation] using the computational procedure given in Paragraph C.4.2., and subsequently compute 3-dimensional differential baseline components.]

*[C.4.9. Real-Time Output. The results of the real-time baseline processing shall be in any user-selected form, such as geocentric coordinates, state plane coordinates based on the North American Datum of 1927, or universal transform mercator projection coordinates. The results will be time tagged with an accuracy of 50 msec, at the time of signal reception at the antenna. The results will be written to a memory device *[both]*[internal and] external to the device performing the computations and shall be sent to an external computer system, at the selection of the user.]

C.4.10. Updates. All baseline processing software updates shall be provided for a period of *[4] years from the date of delivery.

C.5. Network Adjustment Software.

C.5.1. The network adjustment software shall allow for the direct input of data from the post mission processing software specified in Paragraph C.4. The adjustment software shall include routines to easily edit, correct, manipulate, and output results. The software shall have the capability of simultaneously adjusting a minimum of 100 stations. *[The software shall be fully compatible with the microprocessor listed in Paragraph C.3.]

C.5.2. The network adjustment software shall be based on the theory of least squares. It shall be capable of performing both minimally and fully constrained adjustments. Output statistics shall include relative line (distance) accuracies between all points in the network and point confidence limits for each point in the network. Normalized residuals shall be displayed for all input vectors.

C.5.3. The network adjustment software shall transform geocentric coordinates and geographic coordinates to any user defined projection, such as the North American Datum of 1927 state plane coordinate system.

C.5.4. Multiple Copies. The Government shall be allowed to operate the software simultaneously on *[_____] microcomputer systems.

C.5.5. Updates. All baseline processing software updates shall be provided for a period of *[4] years from the date of delivery.

C.5.6. Geoid Modelling. The software shall include the most recent geoid model available to the public from the national geodetic survey.

*[C.5.7. The network adjustment software shall accept and incorporate data from conventional survey methods such as angles, distance, and elevation differences.]

C.6. Data Link for Real-Time Applications.

C.6.1. The data link shall be completely functionally integrated with the receivers and processors procured under this solicitation. This includes the incorporation of modems for the complete interface of radio to processor/receiver.

C.6.2. The data link shall provide data from the reference station to the "roving" station to allow the system to compute positions of the roving station using a kinematic processing technique, as specified in Paragraph C.1. of this solicitation, at a rate of at least one position per second, with no more than one (1) percent loss of position data. The data link equipment shall be identical at both stations to allow transmission from the "roving" station to the reference station. The kinematic processing technique shall not be a function of the data link used. The data link shall transmit all receiver raw observables, as specified in Paragraph C.2. of this solicitation, to the other receiver used in the differential GPS system.

C.6.3. *[The data link system shall operate at the *[VHF frequency of _____]*[VHF frequencies of ___ ___ ___]]. *[The data link shall operate at a frequency that does not require lincensure for use.] *[The data link shall utilize a commercially available carrier phase broadcast that follows the criteria found elsewhere in Section C of this specification. The proposal will include a fee schedule for prescription and monthly service.]

****

NOTE: The frequency used for a VHF broadcast must be coordinated with the FOA frequency manager. Modulation rates and/or channel bandwidth requirements also may have to be specified. The unlicensed frequency will also be low power, hence, very short range.

****

*[C.6.4. The data link shall have an omnidirectional broadcast range of *[8]*[16]*[24]*[32]*[40] km (*[5]*[10]*[15]*[20]*[25] miles) and maintain the positioning capability stated in Paragraph C.6.2.]

****

NOTE: Today, the maximum range of the OTF technology is about 26.6 km (25 miles). Additionally, the longer ranges require increased power, thus, more licensing restriction.

****

*[C.6.5. A mounting kit shall be included to mount the data link antenna to a mast or range pole.]

*[C.6.6. The data link antenna shall be *[suitable for installation on small hydrographic survey launches (less

than 7 m)] *[and]*[have an antenna cable of at least *[____] m]].

*[C.6.7. Power Supply. The data link (including modem) shall operate on the same power source as the GPS receiver.]

C.7. Training.

C.7.1. Upon delivery, the vendor shall provide training of at least *[4] days at *[location] *[to *[4] persons] on the operation of all software and hardware delivered as part of this contract.

*[C.7.2. At a future date, determined by the contracting officer based on coordination with the vendor, and not exceeding 6 months after delivery, the vendor will give an additional *[2] days training at *[location].]

C.8. Miscellaneous Requirements.

C.8.1. All power cables, computer cables, and any other item not mentioned in these specifications needed to make this equipment fully operable shall be furnished as part of this contract.

*[C.8.2. Ruggedized shipping containers shall be furnished for all hardware delivered under this solicitation.]

*[C.8.3. Survey Planning. Survey planning software shall be provided that, as a minimum, includes the following items: tabular and graphic satellite rise/set times, elevations, and azimuths for user-specified geographic locations and times; sky plots of SV positions with provisions for plotting satellite obstructions on the screen; listing of DGOP, PDOP, HDOP, and VDOP; and the selection of specific SV constellations to support in-depth kinematic survey planning.

*[C.8.4. All *[hardware]*[and]*[software] updates will be provided to the Government for a period of * [___] years from the date of delivery, free of charge or delivery cost.]

*[C.8.5. The vendor shall provide repair and maintenance of all hardware delivered under this solicitation for a period of *[___ (--)] years, free of charge.]

****

NOTE: At this point, other unique items may be added to the requirements if called for and/or requiring specification in Section B. Any specific vessel installation requirements for receivers, data links or antenna should be added. As-built vessel drawings or installation sketches should be attached to the contract at Part III, Section J. If DGPS is to be integrated with an existing navigation and/or survey system, manuals, drawings, etc. associated with that system should be referenced and attached at Section J. Both hardware and software connections and modifications to the existing system must be detailed if such effort is to be an item of work under this contract.

****

Section D

Packaging and Marking

D.1. Preparation for Delivery. The system shall be packaged for shipment in accordance with the supplier's

standard commercial practice.

D.2. Packaging and Marking. Packaging shall be accomplished so that the materials will be protected from handling damage. Each package shall contain a properly numbered, dated, and signed transmittal letter or shipping form, in duplicate, listing the materials being transmitted. Shipping labels shall be marked as follows:

U.S. Army Engineer District, ________________
ATTN: {include office symbol and name}
Contract No. ______________________________
[Street/PO Box] {complete local mailing address}

Section E

Inspection and Acceptance

E.1. Acceptance Test. All equipment and related components obtained under these specifications shall be fully certified prior to contract award as meeting the performance and accuracy in Section C. *[Any test previously performed for the Federal Geodetic Control Subcommitee (FGCS) will be acceptable for such certification by the vendor; otherwise the vendor shall be required to demonstrate, at the vendor's expense, the acceptability of the system in the manner prescribed in Paragraph E.2. If the FGCS test is to be used in lieu of a demonstration acceptance test, all results from the FGCS test shall be supplied to the contracting officer for evaluation by technical personnel.]

E.2. Final Acceptance Test. At the option of the Government, a final acceptance test will be performed to demonstrate total system conformance with the technical specifications and requirements in Section C.

E.2.1. The acceptance test will be conducted with the system operating in the modes stated in Paragraph C.1. of this solicitation.

E.2.2. The DGPS positional accuracy will be tested against the accuracy and ranges specified in Paragraph C.1. of this solicitation. The resultant DGPS accuracy will be evaluated with the 1 DRMS error statistic. Inaccuracies in the comparitive testing network / system will be properly allowed for in assessing the test results.

E.2.3. Final acceptance testing will be performed at *[the point of delivery indicated in Section D] *[________________], and will be performed within *[____] days after delivery. The supplier will be notified of the results within *[____] days after delivery. If the equipment fails to meet the acceptance test(s), the supplier will be given *[____] days after notification thereof to make any modification(s) necessary to enable retesting. The supplier will be notified of the place, date, and time of testing and, at his option, may send a representative to attend such tests.

E.2.4. If after a second test, the system fails to perform in accordance with the technical specifications, the Government will *[_____________].

****

NOTE: The applicable contract clause and provisions must be referenced here.

****

E.3. Warranty Provisions. For 1 year after delivery by the vendor, all equipment failures, other than those due to abuse, shall be corrected free of charge. Equipment shall be repaired within 5 working days of receipt at the repair facility, or loaner equipment will be provided at no expense to the Government until repairs are completed and the equipment has been returned to the district. The cost of shipping equipment to the vendor for repair shall be paid by the Government while the vendor will pay for returning the equipment to the District.

Section F

Deliveries or Performance

F.1. Delivery and final acceptance of all equipment shall be made within *[___] days after contract award. Delivery shall be made at the USACE facilities at the address identified in Paragraph D.2. of this solicitation. Final acceptance will depend upon all equipment meeting all requirements specified in this contract.

F.2. The contractor shall deliver all material and articles for shipment in a manner that will ensure arrival at the specified delivery point in satisfactory condition and that will be acceptable to carriers at the lowest rates. The contractor shall be responsible for any and all damage until the equipment is delivered to the Government.

Section G

Contract Administration Data

Section H

Special Contract Requirements

Part II - Contract Clauses

Section I - Contract Clauses

Part III - Contract Clauses

Section J - List of Documents, Exhibits, and Other Attachments

Part IV - Representations and Instructions

Section K - Representations, Certifications, and Other
Statements of Bidders

Section L - Instructions, Conditions, and Notices to Bidders

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NOTE: Add applicable contract clauses and provisions to the above parts/sections as required by the FAR and other supplemental regulations.
****

Part IV - Representations and Instructions

Section M - Evaluation Factors for Award

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NOTE: The following clauses would be used if the solicitation requires an evaluation of proposals for award. See the introduction to this guide for the necessity of a formal proposal evaluation.
****

M.1. Price Basis. Bidders are advised that all bids are solicited on a firm fixed-price basis, and bids submitted on any other than a fixed-price basis will be rejected. Bids submitted on a basis other than free on board (FOB) destination will be rejected.

M.2. Evaluation Criteria.

M.2.1. Technical Factors. The technical part of the proposal shall clearly and fully describe the system to be furnished. Descriptive literature, manuals, and/or reports supplied by the Offeror will be the basis of the evaluation. They should clearly address all items found in the specifications. It is imperative that the Offeror respond to all items in the specifications in like language so the evaluation will compare all products from a common standard. Simple statements such as "conform", which indicate understanding of the requirements, are not adequate. Similarly, phrases which imply or state that the product meets or exceeds the specifications without providing adequate data for the evaluators to make comparisons with those specifications are not adequate.

M.2.2. Pricing Factors. The Offeror shall submit a lump sum firm-fixed-price in accordance with Part I, The Schedule, Section B.

M.2.3. Preliminary Assessment Procedure. A preliminary assessment will be performed to determine if the Offeror's proposal is acceptable or can be made acceptable without major modification.

M.2.4. Evaluation Procedure. The evaluation will be based on the Offeror's compliance with a set of technical requirements consisting of the following items:

(1) System Operational Characteristics and Capacities. This includes, but is not limited to, accuracy, number of independent channels, kinematic capability, data link system performance, ease of operation, and versatility.

(2) System Physical Characteristics and Capacities. This includes, but is not limited to, weight, energy requirements, ease of use, and protection from the environment.

(3) *[Post processing software,] *[network adjustment software,]*[and] field planning software. This includes, but is not limited to, adequacy of software for the specified task, ease of use, documentation, versatility, graphics capabilities, and support.

(4) Warranty, support services, and miscellaneous items.

(5) Proposals will be evaluated on the factors listed above by having assigned values that contribute to a total score. Baseline values will be established by the criteria found in the specifications. Weighting of the scores is in descending order of the above factors, with the most important listed at the top and the least important listed last. A technical team will evaluate each technical proposal and assign a point score. For those proposals that do not meet a pre-established minimum score as submitted, but which the Government decides could be made acceptable by the submission of more information, technical discussions may be conducted to obtain clarification or enhancement of any such proposals. After these discussions, a final point score will be assigned to each proposal by the team.

M.2.5. Proposal Completeness. Failure to submit all required information will result in the proposal not being evaluated.

M.2.6. Number of Technical and Price Proposals. *[One] technical and *[one] cost proposal(s) shall be submitted by each Offeror.

M.2.7. Final Acceptance Test. The system (equipment and/or software) may be required to undergo a final field acceptance test as described in Section E of this contract. Final award shall be contingent on this acceptance test.

M.3. Award Procedures.

M.3.1. The Government will select for contract award the best overall proposal whose final offer is the most advantageous to the Government considering the price and the technical factors included in the solicitation.

M.3.2. The Government may award a contract on the basis of initial offers received, without discussions. Therefore, each initial offer should contain the Offeror's best terms from a cost or price and technical standpoint.

M.4. Suggested Proposal Submittal Requirements.

****

NOTE: The following is a list of hardware and software items/options that should be provided by bidders to determine their capability of providing an adequate DGPS-based positioning system. These items should be tailored to specific system requirements as developed in Section C of this solicitation, and would be used only when technical proposals are being evaluated.

****

M.4.1 GPS Receivers.

Signal levels .
Operation without cryptographic keys.
Observables.
  Measurement time tags.
  Carrier phase signals and accuracy.
  Code phase signals and accuracy.
Receiver output.
Receiver data rate.
PPS output.
Internal receiver testing.

- Reinitialization.
- Multiple satellite tracking.
- Operating conditions.
  - 5 deg SV acquisition.
  - Humidity range.
  - Temperature range.
  - Waterproof.
  - Corrosion resistance.
- Power requirements.
  - Surge protection.
  - Power transfer from AC to DC and reverse.
  - Low power warning.
  - External power source.
  - Battery pack.
    - Charge/recharge capacity.
    - Battery connections/cables.
- Manuals.
- Field planning software.
- Dimensions.
- Weight.
- Data logging device.
- RTCM output.
- RTCM input.
- Waypoints.
- Position update rate.
- Velocity output.
- Antenna.
  - 5/8-in. by 11-in. mounting.
  - Phase center stability.
  - Cable length and quantity.
  - Frequency reception.
  - Environmental considerations.
  - Waterproof.
  - Antenna pole.
  - Tribrach.
  - Vehicle mount.
- Input/Output ports.
  - RS-232 standard.
  - Compatability with other components.
  - NMEA position string.
  - Serial port.

M.4.2. Microcomputer Systems.

- Software/hardware compatibility.
- DOS operating system.
- Processor chip.
- Clock speed.
- Hard drive capacity and access speed.

Random access memory.
3.5-in. disk drive.
VGA graphics adapter.
Power source.
Four extra serial ports (in addition to a mouse port).

M.4.3. Baseline Processing Software.

Compatibility with receivers and microcomputers.
Data computations.
Ephemerides.
Output data.
Batch processing.
Multiple copies.
Absolute point positioning.
Real-time output.
Updates.

M.4.4. Network Adjustment Software.

Compatibility with other software supplied.
100 station minimum.
Theory of Least Squares.
Transformation capability.
Multiple copies.
Updates.
Conventional survey data input.

M.4.5. Data Link for Real-Time Application.

Compatibility with receivers and microcomputers.
1-sec update rate.
Transmission of raw observables.
Frequency.
Broadcast range.
Data loss (less than 1 percent).
Mounting kit.
Power supply.

M.4.6. Training.

At delivery.
At future date.

M.4.7. Miscellaneous Requirements.

Cables, etc.
Shipping containers.
Survey planning software.

Hardware and software updates.
Maintenance and repair.

Appendix I
Guide Specification for Code Phase Differential NAVSTAR Global Positioning System (GPS) Survey Receivers and Related Equipment/ Instrumentation

INSTRUCTIONS

I-1. General

This guide specification supersedes the USACE guide CW-01334.3, 21 June 1991, "Procurement of a Real-Time Differential Global Positioning System (DGPS)". This guide specification is intended for use in preparation and review of specifications for a real-time differential global positioning system (DGPS), generally for use on hydrographic survey vessels and dredges. However, the system may be used for many other applications. The DGPS positions may be computed in real time with the use of the proper data links or, if desired, it may be post-mission processed to generate positions. This guide includes the technical requirements needed to develop formally advertised specifications.

I-2. Applicability

This guide applies to DGPS survey systems providing an expected accuracy of 1 to 6 m (2drms). Typical applications encompass positioning hydrographic survey vessels and dredges in support of Civil Works river and harbor construction. Applications may include any number of activities requiring real-time positioning of moving platforms at the stated accuracy level. The DGPS system specified measures the broadcast code phase to develop pseudo range corrections at a shore-based reference station. (This may be a reference station installed by the USACE, the U.S. Coast Guard, or some other "differential data provider", if the appropriate standard message format is used.) The reference station corrections are subsequently transmitted to the mobile user via a communications link, where the mobile user computes a corrected position based on the mobile GPS data and the received pseudo range corrections. This guide is not intended to support GPS carrier-phase measuring systems that provide centimeter-level accuracies. Refer to Appendix H for differential carrier- based equipment to support higher accuracy applications.

I-3. Coverage

This guide follows the Uniform Contract Format for supply solicitations, as outlined in Part 14.201 of the Federal Acquisition Regulations (FAR).

a. This guide may be used for either direct bid solicitations or proposal request solicitations, depending on the complexity of the required system. Evaluation factors (Part IV, Section M) are provided for contracts involving a technical review of proposals. The use of a technical review is optional.

b. A sample "Supplies of Services and Prices" schedule is included in this guide for insertion in Part I, Section B of the contract. Technical performance requirements for a DGPS survey system are in Part I, Section C (Description/ Specifications). Other contract sections that require clauses specific to DGPS equipment are noted. Nontechnical supply contract clauses/provisions, which are incorporated in Parts I, II, III, and IV of the procurement specifications, should be developed by each respective Field Operating Activity (FOA) using appropriate FAR and supplemental guidance.

c. Continuing developments in DGPS survey instrumentation and techniques mandate that these guide specifications be continuously evaluated by USACE commands to ensure they are technologically current.

I-4. References

The specification author must be thoroughly familiar with the basic GPS functions (e.g., determining the optimum number and technical characteristics of GPS receivers, and auxiliary support equipment and instrumentation) to define the technical requirement options contained in this guide. Additional guidance is found in the HQUSACE POLICY MEMORANDUM, Subject: "Acquisition and Use of Differential Global Positioning System (DGPS) Equipment for USACE Activities," dated 27 January 1994, and topical information on DGPS is contained in EM 1110-2-1003 (Hydrographic Surveying).

I-5. DGPS System Requirements

This guide may be used to procure a complete DGPS real-time survey system. This includes reference station GPS receiver and processor unit, remote (vessel) station GPS receiver and processor unit, a communication link, and onsite training. If GPS receivers are being added to an existing system or suite of equipment, then only the first item would be required in the solicitation, with other items deleted as necessary. Also note that, in general, mixing receivers from different manufacturers may not work with all techniques and software.

I-6. Alternate Clauses/Provisions or Options

Alternate clauses/provisions throughout this guide specification are indicated by a single asterisk. This asterisk signifies that provisions that are not applicable to the particular procurement should be deleted. Clauses requiring the insertion of descriptive material are indicated by an asterisk and in brackets (e.g., *[ ]). When a choice of items exists, they are normally contained in successive brackets.

I-7. Notes and Comments

General comments and instructions used in this guide are contained within asterisk blocks and highlighted in bold type. These blocked comments and instructions should be removed from the final contract.

I-8. Submittal For Review and Approval

If specifications for NAVSTAR GPS survey systems are required to be submitted to higher authority for review and approval, they shall include printed copies of this guide specification, as revised for the particular procurement action. Guidance on review requirements for GPS systems is contained in the HQUSACE POLICY MEMORANDUM, Subject: "Acquisition and Use of Differential Global Positioning System (DGPS) Equipment for USACE Activities", dated 27 January 1994.

Part I - The Contract Schedule

Section A

Solicitation/Contract Form

****

NOTE: Include here Standard Form 33 (Solicitation, Offer and Award) or Standard Form 26 (Award/Contract), as applicable.

****

Section B

Supplies or Services and Prices/Costs

****

NOTE: The sample below represents a typical schedule for procurement of GPS instrumentation and related equipment. This schedule must be tailored based on the specific technical requirements outlined in Section C of the contract.

****

Supplies/Services and Prices

Item No.	Description	Quantity	U/M	U/P	Amt
0001	Real-time DGPS survey system, related equipment, software, data link, and other components, in accordance with the technical specifications found in Section C.	*[___]	EA	___	___

****

Add for RFP evaluation or if necessary

****

* [Evaluation will be made on the basis of the technical data under the guidelines found in Section M. Failure to show compliance with the specifications will require rejection of the bid.]

****

NOTE: The following items are included as separate components if the solicitation is to upgrade or add to existing GPS equipment.

****

Item No.	Description	Quantity	U/M	U/P	Amt
0002	*[Micro-computer system, as specified in Section C.]	___	___	___	___

Item No.	Description	Quantity	U/M	U/P	Amt
0003	* [DGPS post processing and planning, software as specified in Section C.]	___	___	___	___
0004	* [Data link for real-time applications, as specified in Section C.]	___	___	___	___
0005	* [DGPS receiver system, data link, and software training.]	___	___	___	___

****

NOTE: Add other items to the schedule as necessary. These may include spare batteries, data storage devices, communication/modem devices, software/hardware for navigation (e.g., survey vessel positioning and guidance control). Hardware/software interface requirements to existing survey systems (e.g., hydrographic systems) may also be separately scheduled.

****

Section C

Description/Specifications

C.1. General DGPS System Description. The DGPS system to be procured under this solicitation is intended for use in real-time positioning applications using the GPS code phase as the principle observable. The system will yield positions of a "rover" station to an accuracy of *[6 m, 2 DRMS, or better on baselines up to 300 km with respect to a stationary reference station.] *[The system procured under this solicitation will interface to, and operate with, *[the hydrographic surveying package] *[_______]*[and]*[or]*[the electronic display and information system]*[_____].]

C.1.1. General DGPS System Components. Each real-time GPS-based positioning system shall possess at least the following major components:

(1) Integrated GPS receiver/data link receiver-transmitter (referred to as the "DGPS receiver").
(2) Integrated GPS/data link antenna.
(3) Supporting software.
(4) DGPS receiver controller.

C.2. Receiver Requirements. Unless otherwise specified, the performance requirements given below, shall be met by the GPS receivers in conjunction with the antenna assembly and antenna cable.

C.2.1. GPS Signal Levels. GPS receivers delivered shall acquire and track GPS signals and otherwise perform as specified herein, when the signal levels from GPS satellites incident at the antenna are within the range of minimum to maximum levels specified in ICD-GPS-200 REV. B-PR.

C.2.2. Cryptographic Keys. GPS receivers shall perform as specified herein without requiring cryptographic keys, whether or not GPS selective availability (SA) and/or anti-spoofing (AS) are activated.

C.2.3. Code Accuracy. The receiver shall have an l1 C/A-code phase measurement accuracy of 30 cm (RMS) or better, exclusive of receiver clock time and frequency offsets. Signal measurements (observables) shall be time tagged with the time of receipt of the signal, referenced to the receiver clock. Time tags shall have a resolution of 1 μsec or better. Time tags shall be within 1 msec with respect to GPS time.

C.2.4. Receiver Output. The GPS receiver shall be able to output the GPS observables as described in C.2.3. with a latency of less than 1 sec. The GPS receivers shall be able to output the information from the full GPS navigation message, as specified in ICD-GPS-200 REV. B-PR. This shall include ephemeris data, almanac data, ionospheric parameters and coordinated universal time (UTC) parameters. The UTC and ephemeris data shall be available by request or if a change has occurred in those parameters.

C.2.5. Receiver Data Rate. The GPS observable data described above shall be available at a minimum of a 1 Hz rate.

C.2.6. 1 Pulse Per Second (PPS) output. GPS receivers delivered shall have a 1 PPS time strobe and its associated time tag. The 1 PPS pulse and time tag shall be accessible through a port (or ports) on the GPS receiver so that external system components can be time synchronized to UTC time.

C.2.7. Internal Receiver Testing. The receiver shall perform self tests and checks to detect electronic malfunctions and/or faulty data collection, including cycle slips. The receiver shall provide immediate *[audio] *[visual] notification of failures. The receiver shall perform any needed calibrations automatically.

C.2.8. Reinitialization. The receiver shall be capable of reinitializing itself and resume normal operation after a power interruption without operator assistance. The data collected by the GPS receiver shall not be lost due to power interruption but stored in the receiver or other archiving media.

C.2.9. Multiple Satellite Tracking. The DGPS receiver shall be capable of simultaneously and continuously tracking a minimum of six satellites and shall simultaneously and continuously receive and decode the GPS navigation message from each satellite.

C.2.10. Operating Conditions. The GPS receivers, *[including its antenna,] delivered shall meet the following criteria:

(1) Successfully acquire and track unobstructed GPS satellites, visible 5 deg and higher above the horizon, in all weather conditions.

(2) Operate at humidity ranges of 0 to 100 percent.

(3) Operate within the temperature range of -20 °C to +50 °C.

*[(4) Be waterproof and able to operate in an ocean environment aboard open survey launches.]

*[(5) Operate in heavy rain (2 in./day).]

*[(6) Operate in fog.]

*[(7) Operate in and resist corrosion in salty air conditions.]

*[(8) Operate in snow.]

C.2.11. Receiver Power Requirements. The GPS receivers delivered shall:

(1) Be self protecting from power surges, spikes, and reverse polarity.

(2) Allow the operator to switch power sources (AC, DC, or battery) while maintaining receiver operation and without loss of stored data.

(3) Provide a *[visual] *[audible] warning for low power.

(4) Be capable of operating using *[a battery pack] *[and] *[or] *[110-v AC power] *[and] *[or] *[12-v DC power] *[24-v DC power] *[external DC power].

*[(5). The battery pack shall meet the following criteria:]

*[(a) Contain rechargeable battery/batteries that can operate the receiver for at least 3.5 hr on a single (re)charge.;]

*[(b) Be *[either] *[internal] *[or] *[external] to the receiver;]

*[(c) Include all cables, hardware, etc., necessary to connect/install the battery pack. The batteries shall be water and dust tight and protected from damage and inadvertent shorting of the terminals.]

*[(6). For operation using *[AC] *[and] *[external DC] *[power].

*[(a) When operating under *[AC] *[or] *[DC] power, the unit shall be capable of simultaneously charging the battery pack. The battery pack shall power the receiver if the normal power supply is interrupted.]

*[(b) The AC power supply *[shall be internal] *[may be internal or external] to the receiver.]

*[(c) The power supply/battery charger shall provide all voltages necessary to operate the receiver and (re)charge the battery pack.]

*[(d) The power supply/battery charger shall be designed to automatically protect the battery pack from overcharging.]

*[(e) All cables and connectors needed to connect the power supply/battery charger to the power line *[and receiver] shall be included.]

*[(f) The AC power supply/battery charger shall operate from *[115-v] *[and 230-v] AC (±10 percent) *[50/] 60 Hz, single phase power.]

*[(g) The unit shall operate from external *[12-v DC] *[24-v DC] *[9- to 32-v DC] power.]

****

NOTE: Not all manufacturers provide a battery that is internal to the receiver. Moving the battery pack external to the receiver does not affect the functioning; it is a matter of design. For example, moving the battery pack external to the receiver could substantially decrease the size of the unit. The FOA is encouraged to define their requirements and proceed accordingly.

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C.2.12. Manuals. At least two sets of complete operation and maintenance manuals shall be included with each receiver and shall cover all auxiliary components furnished with each receiver. *[Updates shall be furnished as they become available.]

C.2.13. Field Planning. The receiver shall have internal software that, as a minimum, is capable of computing the availability and positions of satellites for any given time and the current position of the GPS receiver using data gathered by the GPS receiver.

C.2.14. Dimensions. The DGPS receiver shall have no single dimension exceeding *[__] cm.

*[C.2.15. Weight. The receiver shall be transportable by one person. [One complete field station consisting of receiver, battery pack, antenna, and antenna cable shall not exceed *[__] kg (__ lbs).]

C.2.16. Data Format. The roving station receiver shall accept and apply correction data in radio technical commission for maritime services special committee 104 (RTCM SC-104), format version 2.1 and the U.S. Coast Guard Broadcast Standards. *[The reference station receiver shall generate pseudo range corrections for each satellite and transmit the corrections in the RTCM format, to be used by the roving station.]

C.2.17. Accuracy. Real-time positioning accuracy relative to the reference station shall be *[2]*[6] m *[2] sigma, or better, within a range of at least 300 km from the reference station.

C.2.18. Position Rate. The receiver shall be capable of providing output position fixes at rates within the range of [__] Hz to [__] Hz.

C.2.19. Velocity. The receiver shall be capable of determining *[velocity and] position while moving at speeds of up to *[__] knots.]

C.2.20. GPS Antenna Assembly.

(1) Antenna Mount. The GPS antenna shall be capable of being mounted on a standard surveyor's tripod with a 5/8 in. by 11-in. threaded stud *[or to a standard wild type tribrach].

(2) Receiver/Antenna Separation. The system shall allow the antenna to be located at least *[30] *[___] m from the receiver such that it can be operated remotely from the receiver with no system degradation.

(3) Antenna Cables. *[One] *[___] antenna cable(s) shall be furnished with each receiver. *[[One] *[each] of these cables should be at least *[__] m,] * [and the other cable should be at least *[__] m.] All appropriate connectors should already be attached to the cable ends. *[These cables shall be capable of being cascaded for a total length of *[___] m of cable for setup flexibility.]

*[(4). Antenna Assembly. The antenna assembly shall include the following criteria:

*[(a) A method to minimize ice and snow buildup.

*[(b) A method to reduce bird nesting capability.]

*[(c) The ability to withstand strong winds up to *[___] knots.]

*[(d) A method to orient (to north) after mounting.]

*[(e) A mechanical mark for height measurement with a known offset from the phase center.]]

*[(7) Be 100 percent sealed/watertight. *[One] *[___] GPS antenna shall be provided with each GPS receiver unit.]

*[(8). Antenna Pole. An antenna pole shall be provided for use during survey operations. It shall be *[a fixed- height pole of 2 m] *[extendable from a length of 1 m (±0.2 m) to 2 m (with a variance of ±0.5m)] and shall allow rapid attachment and detachment of the GPS survey antenna. The pole shall include a built-in leveling device and legs that are *[collapsible and attached] *[detachable].]

*[(9) Tribrach. A standard tribrach (with adapters) shall be provided with each antenna. The tribrach shall allow the antenna to be mounted atop the tribrach. The tribrach shall be able to be mounted on top of a standard surveyor's tripod with a 5/8-in. threaded stud and shall include adapters to allow mounting of standard target sets.]

*[(10) Vehicular Antenna Mount. A survey antenna mount that can easily be attached or detached from the vehicle shall be provided. This mount shall be designed so that it remains firmly in place at speeds of up to 88.5 kmph (55 mph) on a level roadway. The mount shall be designed so that its use does not require vehicle modification.]

C.2.21. Input and Output Ports.

(1) Standards. *[All I/O ports will be compatible with the RS-232 standard.] *[I/O ports shall be compatible with any remote station processor, data terminal or storage devices used in the positioning system.] *[The vendor shall provide complete documentation of the I/O ports including connectors, signal descriptors, connector pin outs, communications protocols, command and message descriptions, required to set up the receiver and extract and decode the observed data.]

****

NOTE: The following option, C.2.21.(2), would be used for differential code position interface to marine systems such as electronic charts or hydrographic survey systems.

****

*[(2) Real-time positional data out of the remote receiver will adhere to the National Maritime Electronics Association (NMEA) 0183 data sentences format and will be output over an RS-232 compatible port.]

C.3. Data Link for Real-Time Applications.

C.3.1. The data link shall be completely functionally integrated with the receivers and processors procured under this solicitation. This includes the incorporation of modems for the complete interface of radio to processor/receiver.

C.3.2. The data link shall provide data from the reference station to the "roving" station to allow the system to compute positions of the roving station using a pseudo range correction processing technique at a rate of at least one position per second, with no more than 1 percent loss of position data. The processing technique shall not be a function of the data link used. The data link shall transmit RTCM special committee 104 v2.1, as specified in Paragraph C.2. of this solicitation, to the other receiver used in the DGPS system. *[The data link equipment shall be identical at both stations to allow transmission from the "roving" station to the reference station.]

****

NOTE: There are several alternatives for the selection of a data link for the transmission of

pseudo-range corrections. Commercial service providers also charge a prescription and/or monthly fee for the corrections.

****

C.3.3. *[The data link system shall operate at the *[VHF frequency of ____]*[VHF frequencies of ___ ___ ___] and transmit power of *[___] w.]. *[The data link shall operate at a frequency and transmit power that does not require licensure for use.] *[The data link shall utilize a commercially available pseudo-range broadcast that follows the criteria found elsewhere in Section C of this specification. The proposal will include a fee schedule for prescription and monthly service.] *[The data link shall be capable of operation at a minimum of 9,600 baud, be minimum shift keying (MSK) demodulation, have a selectable bit rate between 100 and 200 BPS, be able to receive and select desired USCG Radiobeacon Signals in the range of 283.5 to 325.0 kHz, and operate in conditions similar to the GPS receiver specified in Section C.2.10.]

****

NOTE: The frequency used for a VHF broadcast must be coordinated with the FOA frequency manager. Modulation rates and/or channel bandwidth requirements also may have to be specified. The unlicensed frequency will also be low power, hence, very short range.

****

*[C.3.4. The data link shall have an omnidirectional broadcast range of *[8]*[16]*[24]*[32]*[40] km (*[5]*[10]*[15]*[20]*[25] miles) and maintain the positioning capability stated in Paragraph C.10.2.]

*[C.3.5. A mounting kit shall be included to mount the data link antenna to a mast or range pole.]

*[C.3.6. The data link antenna shall be *[suitable for installation on small hydrographic survey launches (less than 7 m)] *[and]*[have an antenna cable of at least *[____] m (___ ft)]].

*[C.3.7. Power Supply. The data link (including modem) shall operate on a *[standard 110-v AC power source]*[and]*[or]*[unregulated 12-v DC power source].]

*[C.3.8. Integrated GPS/Data Link Antenna Assembly. A combined GPS and data link antenna is desired.]

*[C.3.9. Receiver/Antenna Separation. The system, at the roving station, shall allow the antenna to be located at least 22.86 m (75 ft) from the receiver so that it can be operated remotely from the receiver with no system degradation.]

*[C.3.10. Antenna Cables. Two antenna cable(s) shall be furnished with each receiver. One of these cables should be at least 7.62 m (25 ft), and the other cable should be at least 15.24 m (50 ft). All appropriate connectors should already be attached to the cable ends. These cables shall be capable of being cascaded for a total length of 22.86 m (75 ft) of cable for setup flexibility.]

*[C.3.11. Integrated Antenna Mounting. A standard marine mount shall be provided for the integrated antenna to be mounted on top of a survey vessel.]

*[C.3.12. Antenna Assembly. The antenna assembly shall include the following criteria:

(1) A method to minimize ice and snow buildup.
(2) [A method to reduce bird roosting capability.]
(3) The ability to withstand strong winds up to *[100 knots.]

(4) Operation within the temperature range of -40 °C to +65 °C.]

*[C.3.13. Tribrach. A standard tribrach (with adapters) shall be provided with each antenna. The tribrach shall allow the antenna to be mounted atop the tribrach. The tribrach shall be able to be mounted on top of a standard surveyor's tripod with a 5/8-in. threaded stud and shall include adapters to allow the mounting of standard target sets.]

*[C.3.14. Vehicular Antenna Mount. A survey antenna mount shall be provided that can easily be attached or detached from the vehicle. This mount shall be designed so that it remains firmly in place at speeds of up to 88.5 kmph (55 mph) on a level roadway. The mount shall be designed so that its use does not require vehicle modification.]

*[C.4. Receiver Controller.]

*[C.4.1. A receiver controller shall be provided to allow DGPS receiver controls and settings to be modified or changed by the user. This controller may be integral to the GPS receiver and should have the following requirements:]

*[(1) Be capable of running the disk operating system (DOS) 5.0, or later, release date.]

*[(2) Have a minimum of a 486-dx (or equivalent processor) (which has the required math co-processor).]

*[(3) Have a clock speed of at least 66 mHz.]

*[(4) Have a minimum of 200 megabytes (mb) of hard drive, with 20 msec access speed or faster.]

*[(5) Have a minimum of 8 mb random access memory.]

*[(6) Have a minimum of 1 high density 3.5-in. disk drive.]

*[(7) Have a VGA graphics adapter.]

*[(8) Have a minimum of one parallel port and two serial ports.]

*[(9) Have an external monitor port that allows both internal and external monitor display simultaneously.]

*[(10) Be notebook computers.]

*[(11) Have an expansion port or module.]

*[C.4.2. Power. The controller must be able to operate from the same power sources as the receiver.]

*[C.4.3. Environment. The controller must be able to work in the same environment as the DGPS receiver.]

C.5. Software

C.5.1. All software must be provided to change setting and/or configure the GPS receivers.

C.5.2. All software must run on the platform as stated in Section C.4.

C.5.3. The software will allow the GPS differential code phase positions to be computed in a post mission processing mode.

C.5.4. Updates. All post-processing software updates shall be provided for a period of 4 years from the date of delivery.

C.6. Training.

C.6.1. Upon delivery, the vendor shall provide training of at least *[1] day at *[location] *[to *[4] persons] on the operation of all software and hardware delivered as part of this contract.

*[C.6.2. At a future date, determined by the contracting officer based on coordination with the vendor, and not exceeding 6 months after delivery, the vendor will give an additional *[1] day training at *[location].]

C.7. Miscellaneous Requirements.

C.7.1. All power cables, computer cables, and any other item not mentioned in these specifications needed to make this equipment fully operable shall be furnished as part of this contract.

*[C.7.2. Rugged shipping containers shall be furnished for all hardware delivered under this solicitation.]

*[C.7.3. Survey Planning. Survey planning software shall be provided that, as a minimum, includes the following: tabular and graphic SV rise/set times, elevations, and azimuths for user specified geographic locations and times; sky plots of satellite positions with provisions for plotting satellite obstructions on the screen; listing of GDOP, PDOP, HDOP, and VDOP; selection of specific satellite constellations to support in-depth kinematic survey planning; and selection of multiple satellite obstructions.

C.7.4. All hardware and software updates will be offered to the Government for a period of 1 year from the date of delivery, free of charge or delivery cost, or at a set rate as specified by the contract. The Government may, at its option, accept or reject the offered updates. The vendor shall support repair and maintenance of the Government owned configurations of hardware, firmware, and software for a minimum of 5 years after delivery.

*[C.7.5. The vendor shall provide repair and maintenance of all hardware delivered under this solicitation for a period of *[___ (--)] years, free of charge.]

****

NOTE: At this point, other unique items may be added to the requirements if called for and/or requiring specification in Section B.

Any specific vessel installation requirements for receivers, data links, or antenna should be added. As-built vessel drawings or installation sketches should be attached to the contract at Part III, Section J.

If DGPS is to be integrated with an existing navigation and/or survey system, manuals, drawings, etc. associated with that system should be referenced and attached at Section J. Both hardware and software connections and modifications to the existing system must be detailed if such effort is to be an item of work under this contract.

****

Section D

Packaging and Marking

D.1. Preparation for Delivery. The system shall be packaged for shipment in accordance with the supplier's standard commercial practice.

D.2. Packaging and Marking. Packaging shall be accomplished so that the materials will be protected from handling damage. Each package shall contain a transmittal letter or shipping form, in duplicate, listing the materials being transmitted, being properly numbered, dated, and signed. Shipping labels shall be marked as follows:

U.S. Army Engineer District, ________________
ATTN: {include office symbol and name}
Contract No. ____________________________
[Street/PO Box] {complete local mailing address}

Section E

Inspection and Acceptance

E.1. Acceptance Test. All equipment and related components obtained under these specifications shall be fully certified prior to contract award as meeting the performance and accuracy in Section C. *[any test previously performed for the Federal Geodetic Control Subcommitee (FGCS) will be acceptable for such certification by the vendor; otherwise the vendor shall be required to demonstrate, at the vendor's expense, the acceptability of the system in the manner prescribed in Paragraph E.2. If the FGCS test is to be used in lieu of a demonstration acceptance test, all results from the FGCS test shall be supplied to the contracting officer for evaluation by technical personnel.]

E.2. Final Acceptance Test. At the option of the Government, a final acceptance test will be performed to demonstrate total system conformance with the technical specifications and requirements in Section C.

E.2.1. The acceptance test will be conducted with the system operating in *[static] *[dynamic] *[both static and dynamic] mode(s).

E.2.2. The DGPS positional accuracy will be tested against the accuracy and ranges specified in Paragraph C.1. of this solicitation. The resultant DGPS accuracy will be evaluated with the 2 DRMS error statistic. Inaccuracies in the comparative testing network / system will be properly allowed for in assessing the test results.

E.2.3. The data link system will be tested over the operating distance specified in Section C.

E.2.4. Final acceptance testing will be performed at *[the point of delivery indicated in Section D] *[_______________], and will be performed within *[____] days after delivery. The supplier will be notified of the results within *[____] days after delivery. If the equipment fails to meet the acceptance test(s), the supplier will be given *[____] days after notification thereof to make any modification(s) necessary to enable retesting. The supplier will be notified of the place, date, and time of testing and, at his/her option, may send a representative to attend such tests.

E.2.5. If after a second test, the system fails to perform in accordance with the technical specifications, the Government will *[_____________]. {Reference applicable contract clauses/provisions}.

****

NOTE: The applicable contract clause and provisions must be referenced here.

****

E.3. Warranty Provisions. For 1 year after delivery by the vendor, all equipment failures, other than those due to abuse, shall be corrected free of charge. Equipment shall be repaired within 5 working days of receipt at the repair facility, or loaner equipment will be provided at no expense to the Government until repairs are completed and the equipment has been returned to the District. The cost of shipping equipment to the vendor for repair shall be paid by the Government while the vendor will pay for returning the equipment to the District.

Section F

Deliveries or Performance

F.1. Delivery and final acceptance of all equipment shall be made within *[___] days after contract award. Delivery shall be made at the USACE facilities at the address identified in Paragraph D.2. of this solicitation. Final acceptance will depend upon all equipment meeting all requirements specified in this contract.

F.2. The contractor shall deliver all material and articles for shipment in a manner that will ensure arrival at the specified delivery point in satisfactory condition and that will be acceptable to carriers at lowest rates. The contractor shall be responsible for and repair any and all damage until the equipment is delivered to the Government.

Section G

Contract Administration Data

Section H

Special Contract Requirements

Part II - Contract Clauses

Section I - Contract Clauses

Part III - Contract Clauses

Section J - List of Documents, Exhibits, and Other Attachments

Part IV - Representations and Instructions

Section K - Representations, Certifications, and Other
Statements of Bidders

Section L - Instructions, Conditions, and Notices to Bidders

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NOTE: Add applicable contract clauses and provisions to the above parts/sections as required by the FAR and other supplemental regulations.

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Part IV - Representations and Instructions

Section M - Evaluation Factors for Award

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NOTE: The following clauses would be used if the solicitation requires an evaluation of proposals for award. See the introduction to this guide for the necessity of a formal proposal evaluation.

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M.1. Price Basis. Bidders are advised that all bids are solicited on a firm fixed-price basis, and bids submitted on any other than a fixed-price basis will be rejected. Bids submitted on a basis other than free on board (FOB) destination will be rejected.

M.2. Evaluation Criteria.

M.2.1. Technical Factors. The technical part of the proposal shall clearly and fully describe the system to be furnished. Descriptive literature, manuals, and/or reports supplied by the Offeror will be the basis of the evaluation. They should clearly address all items found in the specifications. It is imperative that the Offeror respond to all items in the specifications in like language so the evaluation will compare all products from a common standard. Simple statements such as "conform," which indicate understanding of the requirements, are not adequate. Similarly, phrases which imply or state that the product meets or exceeds the specifications without providing adequate data for the evaluators to make comparisons with those specifications are not adequate.

M.2.2. Pricing Factors. The Offeror shall submit a lump-sum, firm, fixed price in accordance with Part I, The Schedule, Section B.

M.2.3. Preliminary Assessment Procedure. A preliminary assessment will be performed to determine if the Offeror's proposal is acceptable or can be made acceptable without major modification. (The basis for this assessment will be the descriptive literature as called for in Paragraph M.2.1. It is important that this literature be complete, clear, and concise.)

M.2.4. Evaluation Procedure. The evaluation will be based on the Offeror's compliance with a set of technical requirements consisting of the following items:

(1) System Operational Characteristics and Capacities. This includes; but is not limited to; accuracy, number of independent channels, data link system performance, ease of operation, and versatility.

(2) System Physical Characteristics and Capacities. This includes; but is not limited to; weight, energy requirements, ease of use, and protection from the environment.

(3) *[Post Processing Software] *[and] Field Planning Software. This includes; but is not limited to; adequacy of software for the specified task, ease of use, documentation, versatility, graphics capabilities, and support.

(4) Warranty, support services, and miscellaneous items.

(5) Proposals will be evaluated on the factors listed above by having assigned values that contribute to a total score. Baseline values will be established by the criteria found in the specifications. Weighting of the scores is in descending order of the above factors, with the most important listed at the top and the least important listed last. A technical team will evaluate each technical proposal and assign a point score. For those proposals that do not meet a pre-established minimum score as submitted, but that the Government decides could be made acceptable by the submission of more information, technical discussions may be conducted to obtain clarification or enhancement of any such proposals. After these discussions, a final point score will be assigned to each proposal by the team.

M.2.5. Proposal Completeness. Failure to submit all required information will result in the proposal not being evaluated.

M.2.6. Number of Technical and Price Proposals. *[One] technical and *[one] cost proposal(s) shall be submitted by each Offeror.

M.2.7. Final Acceptance Test. The system (equipment and/or software) may be required to undergo a final field acceptance test as described in Section E of this contract. Final award shall be contingent on this acceptance test.

M.3. Award Procedures.

M.3.1. The Government will select for contract award the best overall proposal whose final offer is the most advantageous to the Government considering the price and the technical factors included in the solicitation.

M.3.2. The Government may award a contract on the basis of initial offers received, without discussions. Therefore, each initial offer should contain the Offeror's best terms from a cost or price and technical standpoint.

M.4. Suggested Proposal Submittal Requirements.

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NOTE: Select the appropriate items/options that should be provided by bidders to determine their capability in providing an adequate real-time positioning system. These items should be tailored to specific system requirements.

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M.4.1 GPS Receivers.

Positional accuracy of system.
Signal levels .
Operation without cryptographic keys.
Observables.
    Measurement time tags.
    Code phase signals and accuracy.
Receiver output.
Receiver data rate.
PPS output.

Internal receiver testing.
Reinitialization.
Multiple satellite tracking.
Operating conditions.
  5 deg SV acquisition.
  Humidity range.
  Temperature range.
  Waterproof.
  Corrosion resistance.
Power requirements.
  Surge protection.
  Power transfer from AC to DC and reverse.
  Low power warning.
  External power source.
  Battery pack.
    Charge/recharge capacity.
    Battery connections/cables.
Antenna.
  5/8-in. by 11-in. mounting.
  Phase center stability.
  Cable length and quantity.
  Frequency reception.
  Environmental considerations.
  Waterproof.
  Antenna pole.
  Tribrach.
  Vehicle mount.
Manuals.
Field planning software.
Dimensions.
Weight.
RTCM output.
RTCM input.
Position update rate.
Velocity output.
Ports.
NMEA 0183 data string.

M.4.2. Data Link.
Functional itegration.
1 percent data loss.
Transmit/receive frequency.
Transmit/receive power.
Baud rate.
Prescription fee.
Service fee.
Antenna mounting.
Cables.
Power supply.

M.4.3. Receiver Controller.

Software/hardware compatibility.
DOS operating system.
Processor chip.
Clock speed.
Hard drive capacity and access speed.
Random access memory.
3.5-in. disk drive.
VGA graphics adapter.
Monitor.
Ports.
Power source.
Environment.

M.4.4. Software.

Compatibility with receivers and microcomputers.
Differential code phase processing, post mission.
Receiver control settings.
Field mission planning.

M.4.5. Training.

At delivery.
At future date.

M.4.6. Miscellaneous Requirements.

Cables, etc.
Shipping containers.
Survey planning software.
Hardware and software updates.
Maintenance and repair.